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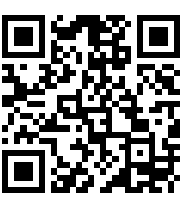

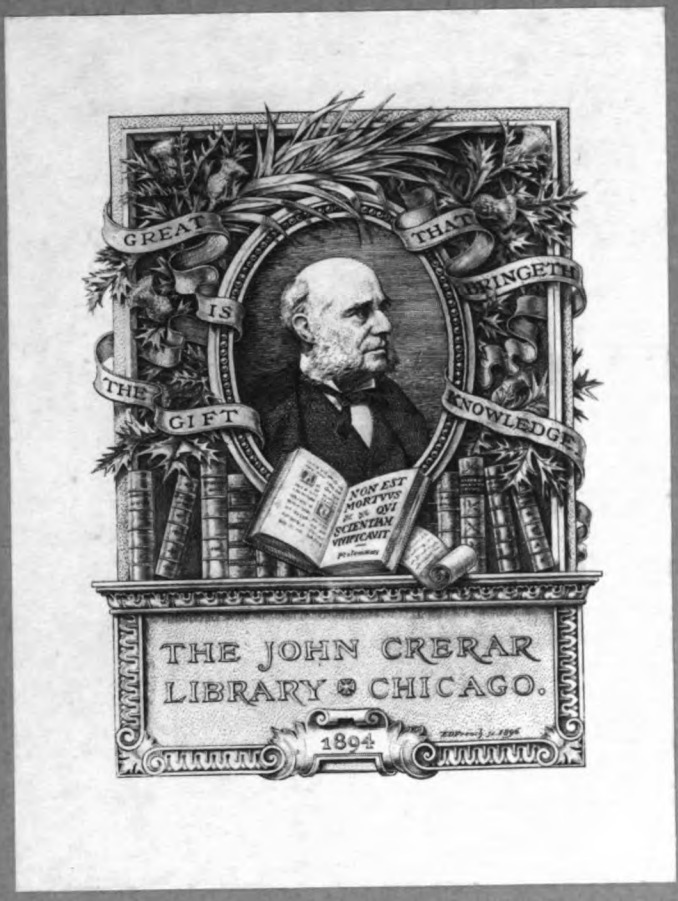
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SPECIAL REPORT NO. 1

A DISCUSSION OF THE PRACTICAL SYSTEMS OF DIRECTION-FINDING BY RECEPTION

By R. L. Smith-Rose, Ph.D., M.Sc., D.I.C., A.R.C.S., A.M.I.E.E., & R. H. Barfield, B.Sc., A.C.G.I.

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PREFATORY NOTE

THE following paper is the first of a series of Special Reports dealing with the work of the Radio Research Board established under this Department.

The investigations described have been carried out by the authors on behalf of the Directional Wireless Sub-Committee of the Board chiefly at the Radio Research Board's Station at the Admiralty Compass Observatory, Ditton Park, Langley, Bucks.

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A DISCUSSION OF THE PRACTICAL SYSTEMS OF DIRECTION-FINDING BY RECEPTION

INTRODUCTORY

OF the various systems of radio-telegraphic direction-finding in use at the present time, there are three distinct types, viz., Single frame coil, the Bellini-Tosi, and the Robinson system.

All these systems operate upon the principle that the magnitude of the E.M.F. induced in a vertical loop by an arriving electromagnetic wave depends upon the angle between the plane of the loop and the wave front. The systems are also similar in that the observation of apparent direction is carried out in each case by setting some part of the rotating system, which revolves about a vertical axis, in a position in which the signal E.M.F. received is zero, or at least, a minimum.

The first use of the single frame coil for radio direction-finding is claimed by Fessenden in 1899[1], and further work was carried out on it by Round in 1905[2], Pickard in 1907[3] and Braun in 1914[4].

Recent developments of this system arising from the use of triode amplifiers therewith, have been largely carried out in France and America, although the British Army made some use of it during the European War.

Artom in 1903 and Bellini and Tosi in 1907 suggested and used large frames of a triangular shape, with the ends open at the top apex and the receiver located at the midpoint of the base for directional wireless communication. The arrangement developed from this and now generally known as the Bellini-Tosi system was fully described in 1908[5], and has been largely used for direction-finding at land and ship installations in both France and this country. The development and use of the system during the war was well described by H. J. Round in 1920[6].

[1] R. A. FESSENDEN, The Fessenden Pelorus, *Electrician*, 1919, **83**, 719–21.

[2] H. J. ROUND, Direction and Position Finding, *Journal I.E.E.*, 1920, **58**, 229.

[3] G. W. PICKARD, An Underground Closed Circuit for Receiving Wireless Signals, *Electrician*, 1907, **59**, 563; also Static Elimination by Directional Reception, *Proc. Inst. Radio Engineers*, 1920, **8**, 366 and 372; and U.S. Patent 956, 165/1907.

[4] F. BRAUN, Use of Closed Circuits in Wireless Telegraphy, *Jahrbuch der Drahtlose Telegraphie*, 1914, **8**, 1.

[5] E. BELLINI and A. TOSI, A Directive System of Wireless Telegraphy, *Electrical Engineering*, 1907–8, **2**, 771–5, and **3**, 348–51.

[6] See Ref. 2, pp. 225–247.

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The Robinson system was described by its inventor in 1920[1], and has been largely used for navigational work on aircraft and also to some extent on ship and shore stations.

There is no essential difference in the basic principle of any of the systems, for in each case the reading of the direction is made as the result of some portion of the system rotating about a vertical axis being set in the position in which there is a minimum, or in the ideal case, zero E.M.F. induced by the incoming waves. The methods of assembling the apparatus and detecting the above setting differ, but these do not affect the main result. The theoretical proof of this is given in the subsequent portions of this report and is followed by experimental confirmation. The results of the experiments also show that whereas each of the three systems is accompanied by its own peculiar instrumental and observational errors, these are at present only of secondary importance by comparison with the variable errors normally experienced, by both day and night, and to which each of the systems is subject to the same degree. The experimental work is considered to settle a controversy which has existed for some time as to the relative "night" errors experienced by small and large coils. (See, for example, the discussion on Round's paper above[2].)

PART I. SIMPLE THEORY OF DIRECTION FINDERS

1. *General Theory of a Closed Loop in an Electromagnetic Field*

CONSIDER a single turn plane conducting loop of any shape enclosing an area A situated with its plane vertical in the electromagnetic field of an advancing wave, and let the loop be pivoted about a vertical axis.

Let it be assumed that the wave front of the wave is sensibly plane but not necessarily vertical. The wave front plane may be inclined at any angle to the earth's surface and the magnetic field may lie in any direction in the wave front.

Let the magnetic field at the point where the loop is situated be resolved into two components at right angles—the one horizontal and the other vertical. Then, since the plane of the loop is vertical, the latter component can never link with it and may therefore be neglected as regards its effect on the loop.

Let the direction of the horizontal component, of the magnetic field make an angle of $90° - \alpha$ with the plane of the loop, as in Fig. 1, and let its maximum value be H_m; also let E_m be the maximum value of the E.M.F. induced in the loop. Then, if the length of the waves be great compared to the linear dimensions of the loop,

$$E_m = KA \cos \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

[1] J. Robinson, A Method of Direction-finding of Wireless Waves and its applications to Aerial and Marine Navigation, *Radio Review*, 1920, **1**, 213–219, 265–275.

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where A is the area of the loop and $K = \omega H_m$, ω being the periodicity corresponding to the waves.

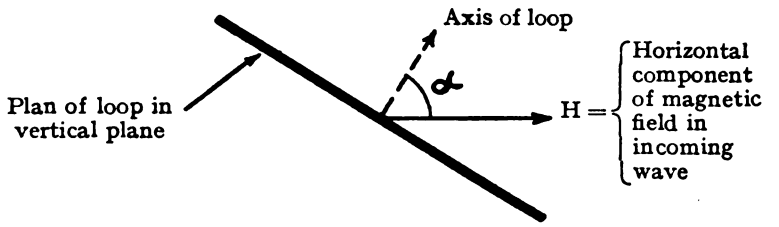

FIG. 1. PLANE VERTICAL LOOP IN PATH OF ELECTRO-MAGNETIC WAVES.

When the loop is turned into such a direction that the E.M.F. induced in it is zero, we shall have $\alpha = 90°$, and the loop will then lie in the vertical plane containing the direction of the resultant magnetic field in the wave front. In certain common cases, subsequently discussed, this plane is perpendicular to the vertical plane containing the direction of travel of the waves and from this fact arises the possibility of utilising the arrangement as a direction-finder.

2. *The Single Coil Direction-finding System*

The single coil system is a very close approximation to the simple theoretical case already discussed, its chief points of departure being as follows :—

(*a*) The coil usually has several turns instead of a single turn, and the separate turns do not necessarily lie in the same plane.

(*b*) A tuning condenser and detecting apparatus are usually connected in the circuit.

As regards the first point, if it could be assumed that the several turns were all condensed into the space occupied by a single turn we should simply get, instead of (1),

$$E_m = KP \cos \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where P is the quantity (area × turns) for the coil.

In practice, however, the turns cannot coincide. They are therefore spaced either in a series of equally dimensioned loops in nearly parallel planes (box type coil), or are wound spirally in the same plane (pancake type coil).

In the case of the pancake winding, the law expressed in equation (1) still holds good, but the quantity A must now stand for the effective or mean area of the coil.

In the case of the box coil, as depicted in Fig. 2, however, a little consideration will show that there is a possibility of obtaining an effective turn of wire whose plane is practically at right angles to the main turns of the coil. In the usual mode of winding a box-shaped coil, the wire commences at one end and is wound slightly askew to the axis to give a definite pitch of the coil from end to end ; this results in the enclosure by the wire

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and the leads to the coil of a certain area in a plane perpendicular to that of the main coil. Since the transference of wire from end to end in a normal coil takes place equally over the main turns, the effective area of this equivalent turn will be $\frac{1}{2}$ A′, where A′

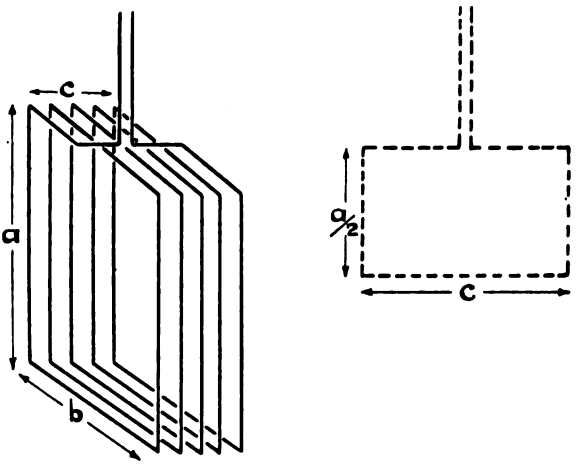

FIG. 2. BOX-SHAPED COIL AND "EQUIVALENT TURN" EFFECT.

is the area of the vertical side of the coil (*i.e.* height × depth of winding).

We may now consider the effect of this extra equivalent turn in series with the main coil on the E.M.F.'s induced in the circuit.

The total E.M.F. E will now be the sum of the E.M.F. (E′) induced in the main coil considered as a number of loops in parallel planes, and the E.M.F. E″ induced in the equivalent extra turn whose plane is perpendicular to the main coil. We shall thus have

$$\begin{aligned} E_m &= E'_m + E''_m \\ &= \omega H_m P \cos \alpha + \omega H \frac{A'}{2} \sin \alpha \\ &= \omega H_m \sqrt{(P)^2 + \left(\frac{A'}{2}\right)^2} \cos (\alpha + \delta) \\ &= KP' \cos (\alpha + \delta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3) \end{aligned}$$

where $P' = \sqrt{(P)^2 + \left(\frac{A'}{2}\right)^2}$

and $\delta = \tan^{-1} \frac{A'}{2P}$.

From the similarity between equations (3) and (2), it is clear that the box wound coil of the usual type is equivalent as regards

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its directional properties to a single turn loop with its plane inclined at a fixed angle $\delta = \tan^{-1}\frac{A'}{2P}$ to that of the mean plane of the true coil and having area × turns of $\sqrt{(P)^2 + \left(\frac{A'}{2}\right)^2}$. If A′ is small, the error involved in assuming the resultant coil coincident with the true coil may be negligible, which holds for most of the cases met with in practice. With a typical box coil as used in the experiments to be described later, the angle δ was calculated to be about 0°·1—quite negligible for ordinary purposes. Should later developments make it desirable entirely to eliminate this error, a box coil may be wound with each turn of wire accurately located in a single plane, perpendicular to the axis of the coil, the connections between the successive turns taking place at the top of the coil in a direction practically parallel to the axis, as shown in Fig. 3. At the expense of a slight increase in the self-capacity of the coil, the area of the equivalent turn becomes reduced to zero.

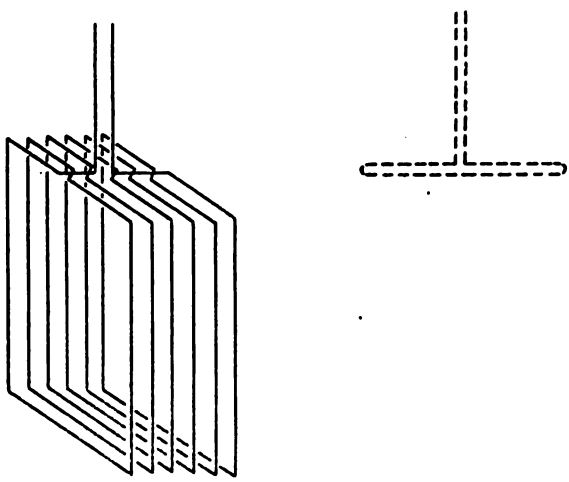

FIG. 3. BOX-SHAPED COIL WITH "EQUIVALENT TURN" EFFECT REDUCED TO ZERO.

As regards (*b*) above, in the practical use of such a single coil system for the determination of direction, a variable condenser is introduced across the ends of the coil and adjusted to give resonance to the incoming waves. The resulting alternating potential difference across this condenser is then employed to operate the detecting amplifier arrangement to give audible response to the incoming waves (Fig. 4A).

When the above condenser is connected to the loop and the resonance condition obtained, the current in the loop from equation (2) will be

$$I_m = \frac{E_m}{R} = \frac{KP\cos\alpha}{R} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

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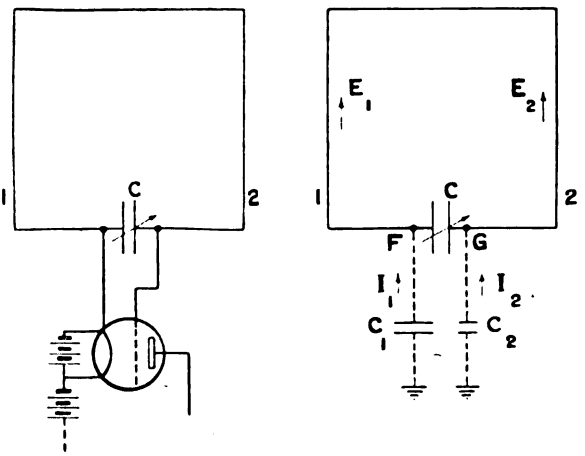
Where R is the effective resistance of the loop under the prevailing radio conditions. The value of R depends not only upon the dimensions of the loop and the frequency being employed,* but also upon the nature and circuit of the detecting arrangements.†

The value of the P.D. across the condenser resulting from the current I_m will be

$$V_m = \frac{I_m}{\omega C} = \frac{H_m P \cos \alpha}{RC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where C is the capacity of the condenser at resonance.

It is evident, therefore, that the alternating potential difference applied to the detector, varies with the orientation of the coil in precisely the same manner as the E.M.F. induced in the coil.



(*a*) FIG. 4. (*b*)

ARRANGEMENT OF COIL WITH TUNING CONDENSER AND TRIODE DETECTOR.

SHOWING DISTRIBUTION OF CAPACITIES DUE TO TRIODE DETECTOR AND ITS BATTERIES.

Two disturbing features, however, arise from the connection of the detecting apparatus, usually a combined amplifying-detecting arrangement of triodes. Firstly, the leads and whole circuit of the latter may pick up a small E.M.F. from the incoming waves, which will be independent of the orientation of the coil. While this E.M.F. may be small compared with the maximum value of V_m (*i.e.* when $\cos \alpha = 1$) it may be quite sufficient to give a very audible signal when $V_m = 0$ (*i.e.* at $\cos \alpha = 0$). The result will therefore be a "blurring" of the zero of V_m into a more or less ill-defined minimum, which may considerably spoil the accuracy of the determination of the

* A. S. BLATTERMAN, Theory and Practical Attainments in the Design and Use of Radio Direction-finding Apparatus using Closed-coil Antennas. *J. Franklin Institute*, 1919, **188**, 289–362.

† J. HOLLINGWORTH, Notes on the Design of Closed Coil Receiving Sets, *Wireless World and Radio Review*, 1922, **10**, 351–354.

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position of the coil for which $\alpha = 90°$. Secondly, due to the capacity to earth of the valve apparatus connected across the condenser, vertical capacity currents will flow to earth from the two vertical sides of the coil. In general these currents will be unequal due to the capacity to earth of the grid of the first valve being much smaller than that of the filament with its associated batteries (compare Fig. 4*b*). The inequality of these two currents results in a P.D. across the condenser C, even when there is no circulating current in the coil itself Dependent also upon the inductance of the vertical sides of the loop and their capacity to earth, the phases of these currents will vary, but in general the resultant P.D. produced across the condenser by these currents is practically in quadrature with that produced by the circulating currents, as evidenced by the ill-defined zero of signal strength, which is obtained on a coil possessing appreciable " vertical " or " antenna " effect. Another result of this vertical effect on a rotating coil system is that in a complete rotation the two minima of signal strength are not exactly 180° apart, due to the non-directional properties of the superimposed P.D. resulting from the above antenna currents.

While various means of overcoming this defect on the single coil direction finder have been suggested, the most successful appears to be the use of a compensating condenser connected between the grid of the first valve and earth, by which the smaller capacity C_2 (Fig. 4*b*) is increased to be equal to C_1. In this case the two " antenna " currents become equal and produce no resultant P.D. across condenser C.

3. *The Bellini-Tosi Direction-finding System*

In this system two large loops, usually of a single turn and of rectangular or triangular shape, are erected with their planes at right angles. In series with each loop is connected a small field coil. These two field coils are also mounted with their planes at right angles, and preferably parallel to the planes of their respective loops, and a small search coil is pivoted so as to rotate within them. The axis of the search coil carries a pointer which moves across a horizontal circular scale divided in degrees.

The aerial loops and field coils of such a system are represented diagrammatically in figure 5 (*a*) and (*b*). Consider a wave front of the same general type as assumed for the case of the single coil and let the horizontal component of its magnetic field make an angle $(90° - \alpha)$ with the plane of the loop A. As before, the vertical component cannot affect either loop, and so may be neglected.

Applying equation (1) above to this case and employing the same notation, we have

$$E'_m = KA \cos \alpha$$
$$E''_m = KA \sin \alpha$$

where E'_m and E''_m are the circulating E.M.F's induced in the loops A and B respectively and A is the area of each loop.

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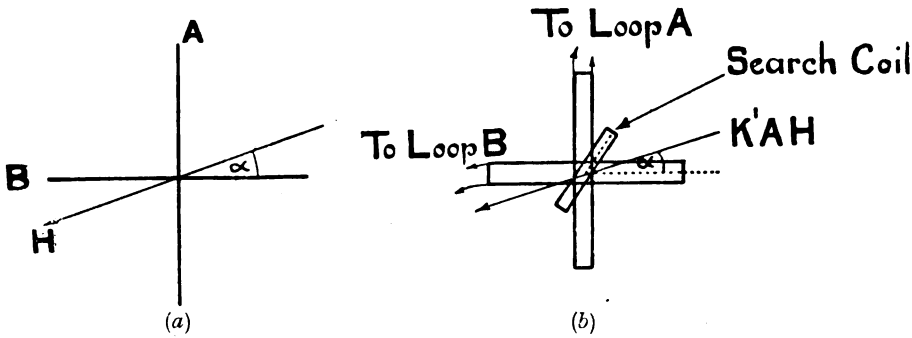
Now the magnetic field produced by the two field coils will be in the direction of their axes and proportional in magnitude to the current in each loop, that is, assuming an identity of the electrical constants of the loops whether they be tuned or untuned, proportional to E_A and E_B respectively.



(*a*) PLAN OF AERIAL LOOPS. (*b*) DIAGRAM OF GONIOMETER.

FIG. 5. SCHEMATIC DIAGRAMS OF BELLINI-TOSI SYSTEM.

Hence, assuming the search coil is so small that the field is sensibly uniform over its area, we have :—

$$\left.\begin{aligned} H'_m &= K' \cos \alpha \\ H''_m &= K' \sin \alpha \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where H′ and H″ are the fields in question and K′ is a constant depending on the area and constants of the loop circuits and the frequency of the waves. It is clear that the resultant of these two components H'_m, H''_m will have a value :—

$$H'''_m = K'H_m \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

and will lie in a direction making an angle α with the axis of the field coil A.

Thus a field is obtained from the field coils reproducing as it were in miniature the main field in which the two loops are situated, *i.e.*, the strength of the field is some definite fraction of the main field which is independent of the direction of arrival of the waves relative to the loops while the direction of this field makes with the axis of the field coil A the same angle which the main field makes with the loop A.

Hence the search coil turning within the field coils is equivalent to a single rotating coil directly receiving the energy of the waves. It is thus possible to determine the direction of the waves by rotating the search coil to find the position where the currents induced in it are zero or a minimum.

The Bellini-Tosi system is thus in theory exactly equivalent to the ideal single-turn rotating loop, and as will be shown later, its practical differences are only of secondary importance. Like the rotating coil direction-finder, it is liable to a certain amount of " antenna " effect, that is, the P.D. across the detector

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may not be entirely due to the circulating E.M.F's in the loops for the same reason as in the case of the rotating coil. It may also be noted that the necessity with this system for exact similarity of the two loops with their circuits and their accurate setting at right angles to one another introduces a number of possible sources of error (due to non-fulfilment of these conditions) which are not present in the case of the rotating coil system.

4. *The Robinson Direction-finding System*

In this system the two coils A and B (figure 6) are fixed rigidly at right angles and pivoted about a vertical axis O.

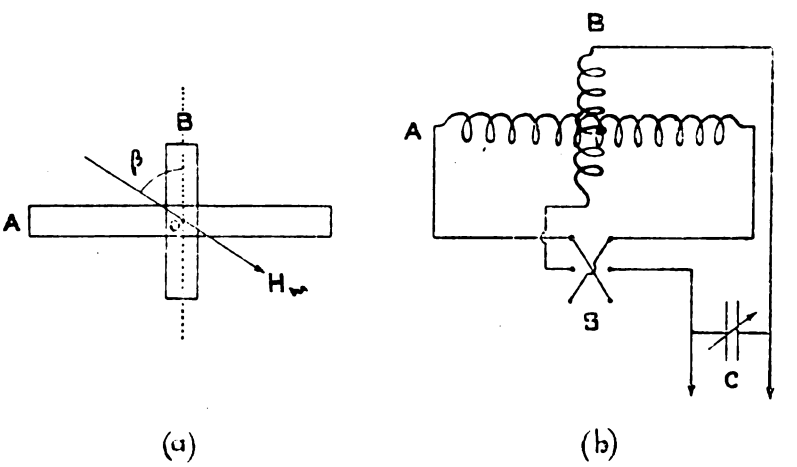

FIG. 6. PLAN OF COILS AND DIAGRAM OF CONNECTIONS OF ROBINSON SYSTEM OF D.F.

The two coils are connected in series and one of the coils can be reversed with regard to the other by means of a switch.

Let area turns of coil A be P.
Let area turns of coil B be Q.

Let H_m make an angle $(90° - \beta)$ with the effective plane of the coil A. Then, if E_A and E_B be E.M.F.'s in A and B, respectively, and there is no mutual induction between the two coils, we have

$$E'_m = \omega H_m P. \cos \beta$$
$$E''_m = \omega H_m Q. \sin \beta.$$

But since the two coils are in series, we have for the resultant E.M.F. in the circuit

$$E'''_m = \omega H_m (P \cos \beta \pm Q \sin \beta)$$

The sign in the bracket being negative or positive according to the position of the reversing switch.

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If now we choose an angle ϕ such that

$$\tan \phi = \frac{P}{Q}$$

we can write

$$E'''_m = \omega H_m (\cos \beta \cos \phi \pm \sin \beta \sin \phi)\sqrt{P^2 + Q^2}$$

i.e.,

$$E'''_m = \omega H_m \sqrt{P^2 + Q^2} \cos (\beta \pm \phi) \ldots\ldots\ldots (8)$$

but this is of the same nature as the expression obtained in (2) for the single turn loop for it can be written $E'''_m = KP'' \cos \alpha$ where

$$P'' = \omega H_m \sqrt{P^2 + Q^2} \text{ and } \alpha = (\beta \pm \phi)$$

From this it can be seen that the system is equivalent to a resultant single coil with area turns $= \sqrt{P^2 + Q^2}$ displaced by a fixed angle $\pm\gamma$ from the coil A, where

$$\phi = \tan^{-1} \frac{P}{Q}$$

This movement of an imaginary single coil by operating a switch is very similar to the swinging of a single frame or search coil of a radiogoniometer.

The angle is changed from $+\phi$ to $-\phi$ with relation to the coil A as the switch is reversed.

This resultant coil may be obtained by adding vectorially the area turns of the two coils in the manner shown in Fig 7.

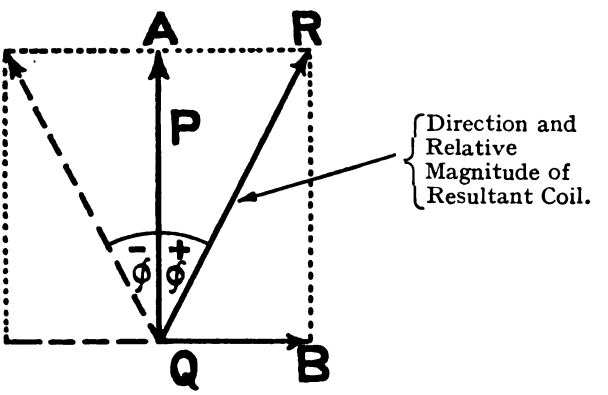

FIG. 7. VECTOR DIAGRAM, ILLUSTRATING "SWINGING" OF RESULTANT COIL IN ROBINSON SYSTEM.

It is thus clear that each time the switch is reversed it is equivalent to displacing a single coil suddenly through an angle of 2ϕ. If, then, as in the method of operating the direction-finder, the whole system be rotated until a position is found in which the signal strength is equal in both positions of the switch, the resultant coil will be alternating between two positions symmetrical about its maximum or minimum position,

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that is to say, the coil A must then lie with its plane parallel to H_m. In this way, therefore, it is possible to determine the direction of arrival of simple types of wave front. The angle of "swing" (2ϕ) of the resultant coil can be made the most suitable value by correctly choosing the ratio of P/Q.

5. *Effect of Inclination and Polarisation of Wave Front on Direction-finders of the above Systems*

It has now been demonstrated that in all general particulars the underlying principle of the three systems of direction-finding described above is the same in all cases; the three systems being simply equivalent to a rotating single turn loop.

In order to see to what extent they can be used for accurate directional determinations with different types of wave front, it is only therefore necessary to consider the behaviour of the simplest (*i.e.* the single coil) in the given circumstances since the conclusions arrived at for this system will be applicable to the other two—(The Robinson and Bellini-Tosi system).

It has been seen that by the ordinary minimum method of operation of the single-coil system it is always possible to determine the direction of the horizontal component (H) of the resultant magnetic field. In practice, however, it is the direction of the horizontal component (D) of the line of motion of the waves which is actually required.

It is clear then that D cannot be determined unless it makes a known angle with H. In practice it is tacitly assumed that D and H are at right angles, although this only applies to the case where either the true direction or the resultant magnetic field or both are horizontal. If neither are horizontal the setting of the coil in its minimum position will have no necessary relation to the direction of arrival of the waves nor to the horizontal component (D) of that direction, and in such a case errors will result. It is interesting to note that a tilted wave front does not necessarily produce directional errors; it may, in fact, be inclined at any angle provided the direction of its magnetic field remains horizontal; and, again, so long as the wave front remains vertical the magnetic field may be directed at any angle therein, without producing any error in the reading of the direction.

PART II. EXPERIMENTAL COMPARISON OF THE ABOVE DIRECTION-FINDING SYSTEMS

6. *Introductory*

THE investigation into the comparative practical operation of the different systems was carried out in three separate experiments, each one entailing daily observations over a period of several weeks. In one of these experiments a sample of all three systems was in use, but in the others only the Bellini-Tosi and Robinson systems were employed. In this work the authors were

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greatly assisted by Mr. S. R. Chapman, B.Sc. The experiments are described in the following sections in the order in which they were carried out.

7. *First Experiment, Comparison of Bellini-Tosi and Robinson Systems, on Damped Waves of Lengths* 2·0 *to* 5·0 *kms.*

(*a*) *Apparatus used*

The Robinson set used was identical with that employed on a large scale by the Radio Research Board for another investigation. The large coil was of dimensions 5′ by 3′, and wound with 30 turns, and the small coil of size 3′ by 2′ 10″ wound with 12 turns. A combined tuner-switch box is mounted on the side of the stand carrying the rotating systems, and leads from this box are taken to the 7-valve combined amplifier-detector, which with its batteries was set up at a distance of several feet from the coil to eliminate any error due to induction.

The Bellini-Tosi set was of the portable land station type, as formerly used by the Army, with a 50′ centre mast, triangular loops with 65′ base and 40′ height. The loops were untuned, earthed at their common centre point and used with tight coupled radiogoniometer and high frequency transformer, constructed with an earthed metallic shield between primary and secondary.

The experiment was carried out at the Slough Research Station of the Radio Research Board, the two sets being situated in a space clear of trees and other obstacles and separated by a distance of about 100 yards, thus reducing mutual interference to a negligible amount. The duration of the experiments was approximately three months, during which time observations were taken simultaneously for several hours on several days in each week. "Night" periods and "Day" periods were worked in about equal numbers, and a definite programme was drawn up so that as far as possible each set was taking an observation on the same transmitting station at the same time.

(*b*) *Results obtained*

The range of wave-lengths dealt with was from 2·0 km. to 5·0 km., and the results from nine different transmitting stations are summarised in the following table No. 1.

With the exception of the North-West quadrant in which few observations were made these stations were fairly well spaced round the compass. Eight of the stations are genuine spark transmitters. The ninth—Horsea—was a C.W. transmitter, but was observable on a spark receiver by reason of the fluctuation in amplitude of wave. Nauen (C.W.) was also received in this way at night.

(*c*) *Discussion of Results*

A comparison of the standard deviation of the systems for each station during the day shows the value of this for the Bellini-Tosi system to be slightly greater than that for the Robinson system.

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TABLE No. I

Summary of Simultaneous Observations on D.F. Sets in Experiment No. 1

R.—Robinson Set B.—Bellini-Tosi Set

1	2	3	Day. 4		5		6		7		Night. 8		9		10		11		12	
Transmitting Station.	True bearing.	λ	No. of obsvns.		Mean.		Standard Deviation.		Permanent error.		Extreme bearings.		No. of obsvns.		Mean.		Standard Deviation.		Maximum variation.	
		km.	R.	B.	R.	B.	R.	B.	R.	B.	R.	B.	R.	B.	R.	B.	R.	B.	R.	B.
	°				°	°	°	°	°	°	°	°			°	°	°	°	°	°
Coltano	132·5	4·1	35	27	133·2	132·6	0·5	0·6	+0·7	+0·1	133·5 132·6	133·7 132·2	17	14	136·3	135·3	2·1	1·4	10·8	7·0
Horsea (C.W.)	207·7	4·5	4	6	207·8	208·1	0·4	0·7	+0·1	+0·4	208·3 207·2	208·5 207·1	6	7	207·7	208·5	1·8	2·6	1·8	8·6
Karlsborg	44·8	2·4 4·2	10	14	43·3	45·3	0·7	0·8	−1·5	+0·5	44·5 42·1	46·3 44·0	87	62	48·4	45·6	7·7	5·0	27·1	28·0
Moscow	64·2	5·0	—	—	—	—	—	—	—	—	—	—	72	69	64·5	65·8	1·8	1·9	9·9	9·2
Nauen (D.W.)	76·9	3·9	11	8	76·3	78·3	0·5	1·5	−0·6	+1·4	77·0 75·7	80·0 77·0	—	—	—	—	—	—	—	—
Nauen (C.W.)	—	4·9	—	—	—	—	—	—	—	—	—	—	10	4	81·8	83·4	—	—	2·0	3·8
Nikolaieff	90·5	4·0	17	16	88·4	89·2	0·5	1·1	−1·1	−1·3	89·7 87·6	91·0 87·5	—	—	—	—	—	—	—	—
		3·2	15	17	144·9	144·9	0·1	0·3	+1·0	+1·0	145·1 144·7	145·3 144·3	—	—	—	—	—	—	—	—
Paris	113·9	2·6	80	43	144·7	144·6	0·3	0·4	+0·8	+0·7	145·7 144·1	145·4 143·7	27	17	144 8	145·1	0·4	1·1	2·2	3·5
Poldhu	245·7	2·8	18	12	245·5	247·9	0·5	−0·5	−0·2	+2·2	245·8 244·0	248·5 247·1	9	7	241·0	244·1	—	—	8·4	10·7
Sofia	109·2	3·2	—	—	—	—	—	—	—	—	—	—	9	20	111·6	112·9	2·6	3·8	7·8	12·3

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The permanent error, *i.e.* the difference between the mean bearing for the period and the true bearing, is of the same order for both systems, varying from $+0°\cdot1$ to $-1°\cdot5$ and $+0°\cdot1$ to $+2°\cdot2$ for the Robinson and Bellini-Tosi respectively. It should be noted, however, that, although of the same order, they are sometimes of different sign. It is not yet clear whether this discrepancy is due to difference in instrumental errors or to the slight difference in the local surroundings of the systems, but further experiments will be carried out to determine this point.

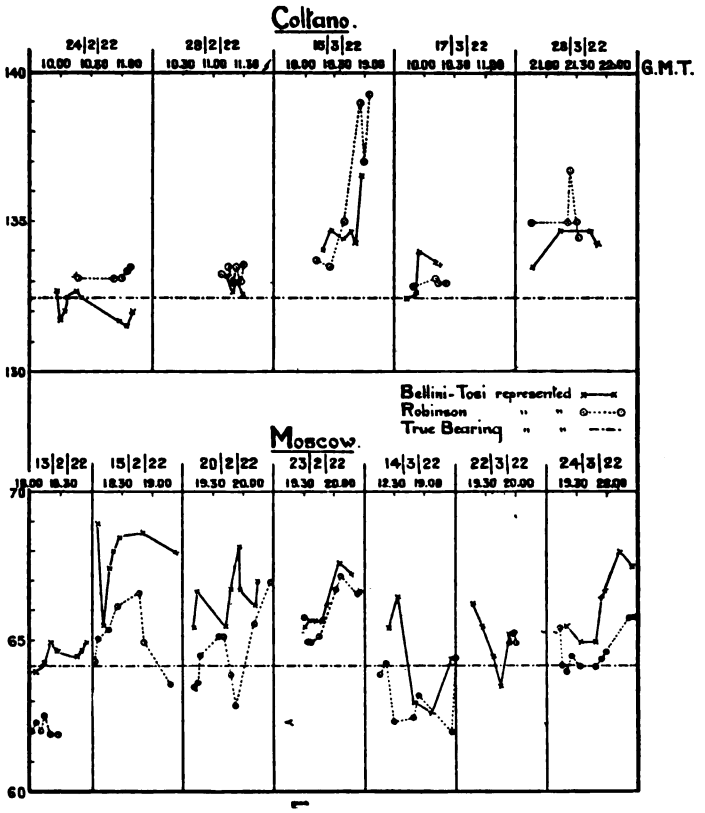

FIG. 8. OBSERVATIONS OF BEARINGS TAKEN AT SLOUGH, WEEKS ENDING:—18TH, 25TH FEB., 4TH, 18TH, 25TH MAR., AND 1ST APR. 1922.

At night both systems show a liability to variable errors of apparently the same amount, the similarity of the maximum variation detected and the standard deviation for each station being very noticeable. The general agreement is most clearly illustrated in the curves on Figs. 8 and 9, which were plotted for the three stations, Coltano, Karlsborg and Moscow. The curves in Fig. 9 give the most convincing evidence of the similarity of the variations on the two systems. It should be noted that the extremely broad minima often accompanying the phenomenon of night-effect might be expected to be the cause

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of large observational errors which might result in some cases, in widely different observations being obtained. This would easily account for the few discrepancies that appear in the table and in the curves.

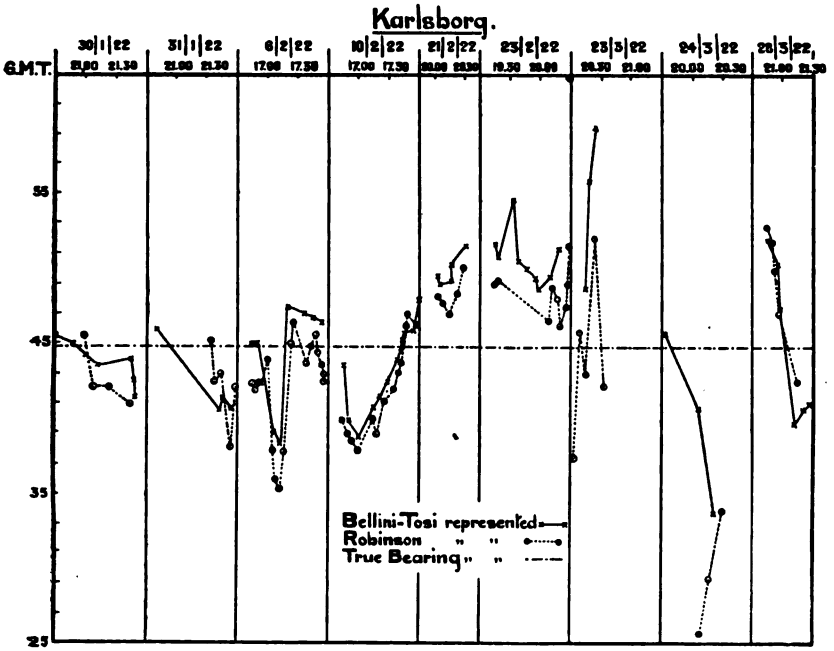

FIG. 9. OBSERVATIONS OF BEARINGS MADE AT SLOUGH, WEEKS ENDING:—4TH, 11TH, 25TH FEB., 25TH MAR., AND 1ST APR. 1922.

The signal strength on both sets was practically the same as indicated by the fact that there was no station which was within range of one set and yet too weak for the other.

8. *Second Experiment, Comparison of Single Frame, Bellini-Tosi and Robinson systems on damped and undamped waves of lengths* 1·8 *to* 9·0 *km.*

(*a*) *Apparatus used*

The single frame-coil used was of a standard form used by the Army, consisting of a collapsible wooden frame 3′ 4″ square wound with two separate coils each of 16 turns. These two windings could be connected in series or parallel by means of a switch for different wave-length ranges. Variable and fixed condensers were used for tuning this coil over the range of wave-lengths used, and a compensating condenser was also used to enable the capacity to earth of the grid of the first valve to be made equal to that of the capacity from filament to earth, thus obtaining sharper minima as mentioned in 3 (*b*) above. This compensating condenser required adjustment for each change

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TABLE No. II

Summary of Results (Day working) in Experiment No. 2

R—Robinson Set B—Bellini-Tosi Set A—Single-coil Set

1	2	3	4			5			6			7			8		
Transmitting Station.	True bearing.	λ (km).	No. of observations.			Mean bearing.			Standard deviation.			Permanent error.			Extreme variation from mean.		
			R.	B.	A.	R.	B.	A.	R.	B.	A.	R.	B.	A.	R.	B.	A.
	°					°	°	°	°	°	°	°	°	°	°	°	°
Aldershot (C.W.)	207·5	1·8	17	18	15	208·8	209·8	208·4	1·1	0·7	0·7	+1·3	+2·3	+0·9	2·3	1·6	1·1
Chelmsford (C.W.)	69·9	3·8	22	36	32	69·4	70·6	69·8	0·4	0·4	0·1	−0·5	+0·7	−0·1	0·9	0·9	0·4
Clifden (C.W.)	292·5	5·8	15	20	12	293·4	293·4	293·3	0·4	0·4	0·3	+0·9	+0·9	+0·8	0·9	1·1	0·5
Cologne (C.W.)	—	1·8	7	9	9	93·3	94·1	95·0	—	—	—	—	—	—	1·8	0·6	1·0
Konigswusterhausen (C.W.) ..	79·2	5·3	8	8	5	79·8	81·7	81·9	—	—	—	+0·6	+2·5	+2·7	1·7	1·6	1·1
Leafield (C.W.)	298·5	8·7	4	4	5	300·0	300·6	300·0	—	—	—	−1·5	−2·1	−1·5	0·9	0·3	0·2
Nauen (C.W.)	76·9	4·9	31	26	23	77·1	78·0	77·4	0·6	0·4	0·7	+0·2	+1·1	+0·5	1·1	0·9	1·1
Northolt (C.W.)	—	6·5	7	8	6	64·1	65·9	65·1	—	—	—	—	—	—	0·5	0·6	0·2
Ongar (C.W.)	64·0	2·9	28	34	27	64·7	67·2	66·4	0·8	0·6	0·3	+0·7	+3·2	+1·7	2·4	1·4	0·9
Paris (S.)	143·9	2·5	18	14	14	144·9	144·8	144·3	—	—	—	+1·0	+0·9	+0·4	0·5	0·7	0·7
Tours (C.W.)	168·1	6·8	4	3	5	170·1	170·2	168·7	—	—	—	−2·0	−2·1	−0·6	0·4	0·3	1·8

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in wave-length of the coil system, but when correctly set, the zeros observed were very sharp and bearings could be read to 0°·1. A 6-valve screened amplifier-detector was used for reception; a separate screened oscillator enabled observations to be made on continuous waves.

The same Bellini-Tosi set was employed as in the previous experiment. As this instrument was not provided with a method of continuous wave direction-finding, however, a separate screened oscillator was used with very satisfactory results.

The Robinson set used in this experiment was of a slightly different pattern to that previously employed, and somewhat more difficult to handle. Both coils were approximately 4′ square, and contained 32 and 12 turns respectively in four sections, which could be connected in series or parallel for different wave-length ranges. A metallic screening box was provided for the oscillator, amplifier and batteries to enable C.W. reception to be carried out.

These sets were erected at the Slough station on the same site as used in Experiment No. 1, and the absence of mutual interference was verified by tests. The experiments were carried out over a period of one month during which time approximately 550 observations were taken, 50 of which were at night; on some occasions all three sets were worked simultaneously, bearings on a given transmitter being taken at the same moment by each operator. On other occasions two of the sets only were worked together, the same method of operating being adhered to.

(*b*) *Results obtained*

A summary of the results obtained during day working is given in Table II. It will be seen that eleven different transmitting stations were observed, and that on these only very slight differences exist between the systems.

The standard deviation was worked out for those transmitting stations on which a sufficient number of readings had been taken, and is given in Column 6. These values indicate that the difference in accuracy of the three sets is practically negligible.

The permanent errors, *i.e.* the day average (Column 6) minus the true bearing (Column 2) are given in Column 7. They vary in the case of the Robinson set from —2°·0 to —1°·0, in the case of the Bellini-Tosi from —2°·1 to —1°·1, and for the single-coil system from —1°·5 to —0°·8.

The results obtained at night are shown in Table III. The method of observation consisted in taking isolated bearings on different transmitters simultaneously on each, or two of the three systems under comparison, rather than a series of bearings on one transmitter. For this reason the variations of individual readings from the day mean have been recorded in this table against the time at which they were taken. It can thus be seen at a glance whether a given error on one system was accompanied by a similar error on the others.

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TABLE No. III

Summary of Results—Night Working—Experiment No. 2

Date and Time.	Transmitter.	Amount of Deviation.		
		Robinson.	Bellini-Tosi.	Single Coil.
1922.		°	°	°
22/5 1950	Chelmsford (C.W.) ..	+ 3·1	+ 1·5	—
15/5 1950	,, ..	0·0	— 1·7	—
19/5 2100	,, ..	+ 1·8	+ 2·4	—
,, 2000	,, ..	+ 2·4	—	+ 2·7
,, 2020	,, ..	+ 2·5	—	+ 2·3
24/5 2050	,, ..	—	— 1·1	— 3·8
,, 2055	,, ..	—	— 0·5	— 0·1
29/5 2150	,, ..	—	+ 2·4	+ 0·2
15/5 2000	Clifden (C.W.) ..	— 0·1	— 0·4	—
,, 2011	,, ..	— 1·9	— 2·4	—
19/5 2015	,, ..	0·0	—	— 0·2
,, 2028	,,	+ 0·8	—	+ 1·2
24/5 2137 to 2147	Horsea (C.W.) ..	—	Min. too broad to get a bearing.	Min. too broad to get a bearing.
19/5 2010	Konigswusterhausen C.W.)	— 1·0	—	— 4·0
29/5 2136	Konigswusterhausen (C.W.)	—	+ 3·8	+ 3·1
15/5 2007	Nauen (C.W.) ..	+ 5·4	+ 2·5	—
,, 2050	,, ..	+ 4·7	—	+ 3·3
19/5 1958	Ongar (C.W.) ..	+ 0·8	—	— 2·9
,, 2050	,, ..	+ 3·2	+ 1·5	—
22/5 2114	,, ..	+ 2·4	0·0	—
24/5 2018	,, ..	—	+ 0·5	— 1·1
,, 2048	,, ..	—	— 2·1	— 3·1
15/5 1934	Paris, (S)	0·0	— 0·1	—
19/5 2034	Tours (C.W.) ..	+ 1·2	—	— 1·1
24/5 2105.	,, ..	—	— 3·0	— 2·0
,, 2115	,, ...	—	— 1·3	— 1·0

The table shows that in this particular experiment no very large errors were recorded on any of the sets, the greatest deviation from the day mean amounting to 5°·4. It also shows that the errors are of the same order for each system, and that although there is a noticeable agreement between the three systems of some of the individual readings, there is distinct difference between others.

9. *Third Experiment. Comparison of Bellini-Tosi and Robinson systems on damped and undamped waves of length* 2·0 *to* 9·0 *kms.*

(*a*) *Apparatus used*

This experiment was carried out in a different locality, the permanent Bellini-Tosi set at H.M.W/T Station at Orford being

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employed. The aerials at this station were of approximately diamond shape, being supported upon a central mast 92′ high, with corner masts 32′ high. The whole installation was employed as originally erected, the apparatus being arranged with a suitable intermediate circuit for reception on the wave-length range 2·0 to 9·0 km. using untuned aerials and a tight-coupled goniometer. A 6-valve amplifier was employed, and a separate screened oscillator was coupled to this amplifier for C.W. reception; an arrangement which has always been found quite satisfactory for this system.

The Robinson set used in the first experiment was again employed with the addition of a screened oscillator for C.W. reception. The hut containing this set was erected at a distance of 380 feet from the central Bellini-Tosi mast, and tests made showed that there was no mutual interference between the two sets.

(*b*) *Observations obtained*

Regular observations over periods of 3½ to 4 hours per day were carried out on both sets simultaneously over a period of five weeks, a summary of the 2,185 readings obtained being given in Tables IV and V.

(i) *Day readings.*—The observations obtained in the day periods show that on the Bellini-Tosi set the extreme bearings on the different stations vary over a range of from 0°·5 to 7°·5, the corresponding range on the Robinson set being from 0°·2 to 3°·7. The largest variations on the Bellini-Tosi set were obtained on Leafield, being 6°·0 and 7°·5 for the marking and spacing waves respectively, while on the Robinson set the corresponding variations were 1°·3 and 1°·9. On the other hand, the largest variations obtained on Ongar were 3°·7 on the Robinson and 2°·5 on the Bellini-Tosi set.

In general the results in Table IV show that extreme variations from the mean of more than 2° are comparatively rare on either set. It is thus possible that the larger errors on the Bellini-Tosi set mentioned above were observational errors, as these are easily possible when taking quick swings over large angles. On the Robinson set the observations could usually be made to 1° or less in the day-time, so that the possibility of observational errors is much reduced.

The smaller variations of from 1° to 2° on either side of the mean must be taken as definite day variations, since they occur simultaneously on two independent sets. This is now generally recognised as the order of normal day variations.

In spite of these variations, however, it is seen that in most cases the mean bearing on both sets is correct to within a fraction of a degree. In the case of Paris, however, there is a discrepancy of nearly 1° between the two sets, the error on the Bellini-Tosi set being nearly double that on the Robinson set, on both wave-lengths. There is also a discrepancy of more than a degree between the mean bearings obtained on the three transmissions from Ongar.

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TABLE

Day Periods. Observations of bearings of Fixed Transmitting

Bellini-Tosi Set

Transmitting Station.	Type and wave length (km.).	No. of obsns.	Extreme bearings.	Mean bearing.	Total variation.	Maximum variation from mean.
			°	°	°	°
Aberdeen	C.W. 4·2	11	338·5 339·5	339·1	1·0	−0·6
Air Ministry	C.W. 4·1	6	236·2	—	—	—
Budapest	C.W. 4·1	1	—	104·5	—	—
Cleethorpes	C.W. 3·5	—	—	—	—	—
Cleethorpes	C.W. 4·5	—	—	—	—	—
Clifden	C.W. 5·8	7	285·0 285·5	285·1	0·5	+0·4
Coltano	Spk. 4·2	4	140·0 141·0	140·5	1·0	+0·5
Devizes	C.W. 2·1	—	—	—	—	—
Karlsborg	Spk. 2·5	10	42·5 45·0	44·2	2·5	−1·7
Karlsborg	C.W. 3·9	—	—	—	—	—
Konigswusterhausen	C.W. 5·3	23	80·0 84·0	83·0	4·0	−3·0
Leafield (M.)	C.W. 8·8	42	260·0 266·0	263·6	6·0	−3·6
Leafield (S.)	C.W. 8·7	37	258·0 265·5	263·7	7·5	−5·7
Malta	C.W. 4·2	—	—	—	—	—
Moscow	Spk. 4·8	—	—	—	—	—
Nantes	„ 2·6	—	—	—	—	—
Nantes	„ 4·2	5	202·0 205·0	204·4	3·0	−2·4
Nauen	„ 3·2	29	80·0 81·5	80·7	1·5	+0·8
Nauen	C.W. 4·9	3	80·5 81·0	80·7	0·5	+0·3
Nauen	C.W. 6·2	—	—	—	—	—
Ongar	C.W. 2·9	51	243·5 246·0	244·8	2·5	−1·3
Ongar	C.W. 3·8	16	245·0 247·5	246·5	2·5	−1·5
Ongar	C.W. 4·2	118	245·5 247·0	246·2	1·5	+0·8
Paris	Spk. 2·6	124	169·0 170·0	169·5	1·0	+0·5
Paris	Spk. 3·2	11	169·5 170·0	169·6	0·5	+0·4
Prague	C.W. 4·2	2	98·0 98·5	98·3	−0·3	−0·3
Stonehaven	C.W. 3·5	36	335·0 337·0	336·4	2·0	−1·4
Whitehall	C.W. 3·3	12	240·0 241·5	240·9	1·5	−0·9

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No. IV

Stations, made at Orford during period 17th July–19th August, 1922

Robinson Set

No. of obsns.	Extreme bearings.	Mean bearing.	Total variation.	Maximum variation from mean.	True bearing.	Error of mean: B-T.	Error of mean: Robinson.	Remarks.
	°	°	°	°	°	°	° '	
9	339·2 / 338·5	338·9	0·7	−0·4	338·5	+0·6	+0·4	
6	236·2 / 235·0	235·5	1·2	+0·7	—	—	—	
—	—	—	—	—	104·3	+0·2	—	
3	323·6 / 322·5	323·2	1·1	−0·7	326·5	—	−3·3	
4	326·8 / 326·0	326·5	0·8	−0·5	326·5	—	0·0	
—	—	—	—	—	285·6	−0·5	—	
1	141·5	141·5	—	—	141·5	—	—	Too few readings
1	253·3	253·3	—	—	253·6	—	−0·3	
7	44·0 / 43·5	43·9	0·5	−0·4	43·8	+0·4	+0·1	
10	44·1 / 43·8	44·0	0·3	−0·2	43·8	—	+0·2	
43	85·0 / 82·0	83·3	3·0	+1·7	83·6	−0·6	−0·3	
47	264·7 / 263·4	264·1	1·3	−0·7	263·7	−0·1	+0·4	
45	264·9 / 263·0	264·2	1·9	−1·2	263·7	0·0	+0·5	
2	145·1 / 145·0	145·1	—	—	145·3	—	−0·2	
5	66·2 / 65·0	65·4	1·2	—	66·0	—	0·6	
—	—	—	—	—	204·4	—	—	
3	204·0 / 202·5	203·5	1·5	−1·0	204·4	0·0	−0·9	
38	81·2 / 80·1	80·9	1·1	−0·8	80·9	−0·2	0·0	
19	82·0 / 80·2	80·9	1·8	+1·1	80·9	−0·2	0·0	
11	81·8 / 80·2	81·1	1·6	−0·9	80·9	—	+0·2	
46	244·9 / 241·8	243·7	3·1	−1·9	246·0	−1·2	−2·3	
35	247·5 / 243·8	245·1	3·7	+2·4	246·0	+0·5	−0·9	
96	246·5 / 243·0	244·7	3·5	+1·8	246·0	+0·2	−1·3	
129	170·8 / 170·1	170·4	0·7	+0·4	171·3	−1·8	−0·9	
16	170·4 / 170·2	170·3	0·2	0·1	171·3	−1·7	−1·0	
—	—	—	—	—	99·0	—	—	Too few readings
10	339·6 / 337·6	338·7	2·0	−1·1	336·9	−0·5	+1·8	
—	—	—	—	—	241·1	−0·2	—	

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(ii) *Night readings.*—Table V gives a summary of the observations made during the evening periods. All the recorded readings are here given except those from the stations upon which less than 10 observations were made. Excluding Paris, it is seen that the total variations at night range from 5°·0 to 54°·0 for the Bellini-Tosi set, and from 5°·2 to 51°·3 for the Robinson set.

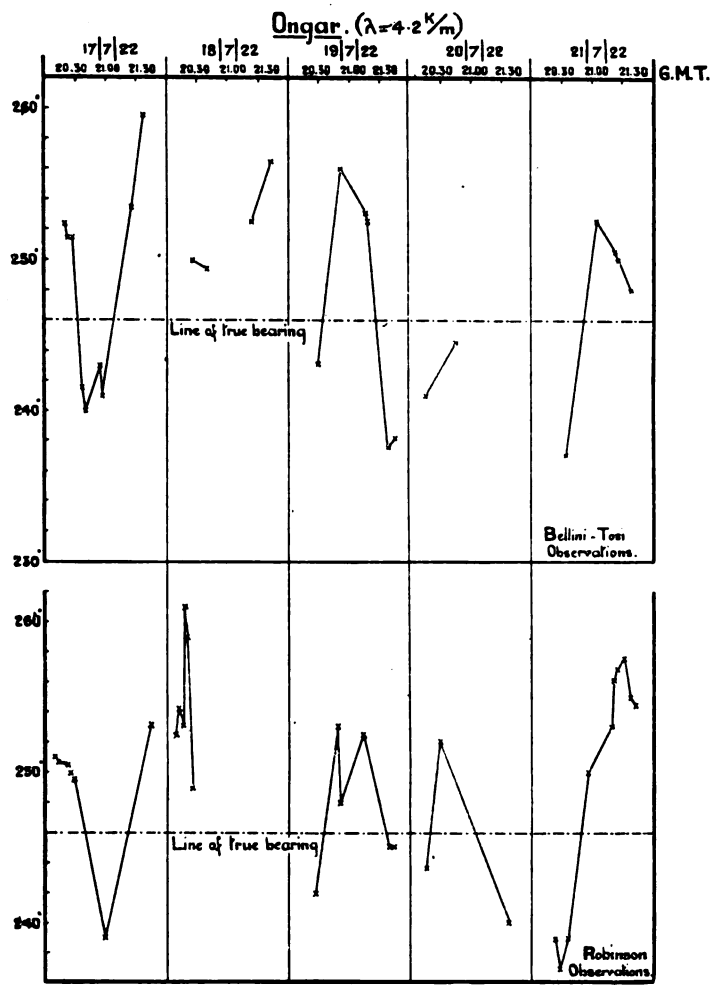

FIG. 10. OBSERVATIONS OF BEARINGS MADE AT ORFORD, WEEK ENDING 22ND JULY, 1922.

In each case the variations and the systematic errors of the means are of the same order for each set. This identity of variation is well shown up in figures 10 and 11, in which the nightly observations on Ongar and Leafield for a week each are plotted. The manner of the variation of Leafield's marking and spacing waves on 17–8–22 is particularly noteworthy.

In the case of Paris the variation on either set is very small.

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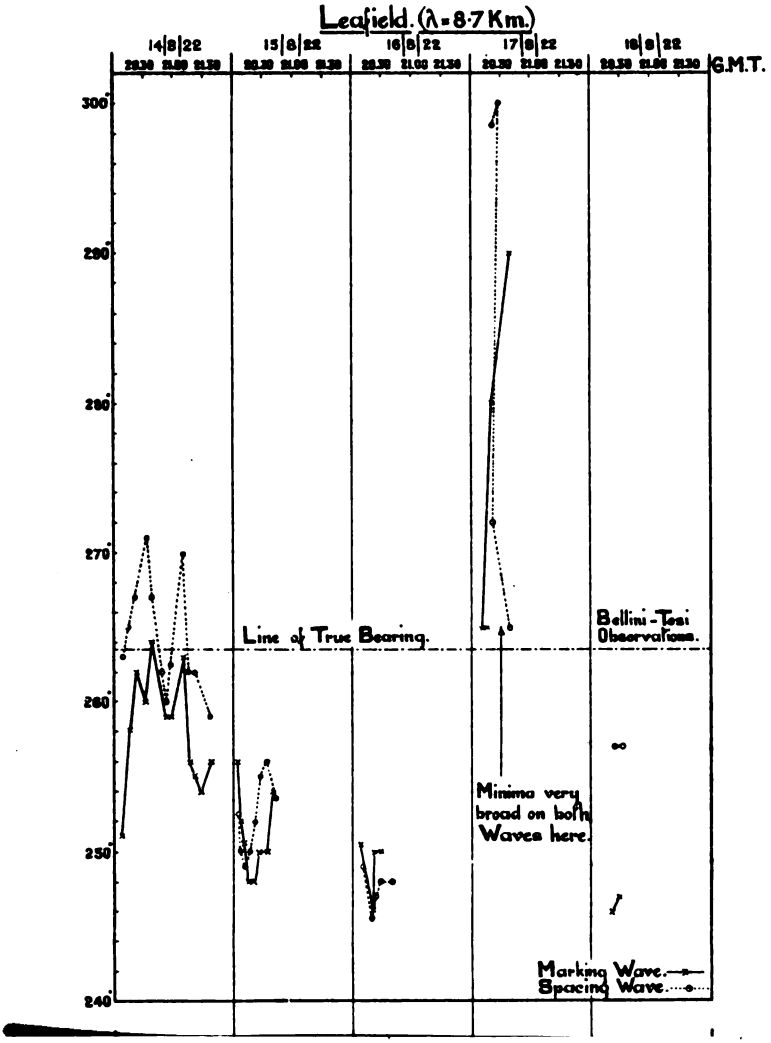

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Evening Periods. Observations of Bearings of Fixed Transmitting Stations, made at Orford during period 17th July–19th August, 1922

	Bellini-Tosi Set.						Robinson Set.							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Transmitting Station.	Type and wave length (km.).	No. of observations.	Extreme bearings.	Mean bearing.	Total variation.	Maximum variation from mean.	No. of observations.	Extreme bearings.	Mean bearing.	Total variation.	Maximum variation from mean.	True bearing.	Error of mean, B.T.	Error of mean, Robinson.
			°	°	°	°		°	°	°	°	°	°	°
Clifden	Spk. 5·8	—	—	—	—	—	10	281·5 273·0	278·4	8·5	− 5·4	285·6	−0·6	−7·2
Karlsborg	Spk. 2·5	35	42·5 65·0	51·6	22·5	+ 13·4	51	66·5 33·0	52·0	33·5	−19·0	43·8	+7·8	+8·2
Konigswusterhausen..	C.W. 5·3	18	73·0 88·5	83·1	15·5	− 9·9	12	126·5 83·0	93·7	43·5	+32·8	83·6	−0·5	+10·1
Leafield (M.)	C.W. 8·8	66	246·5 290·0	258·4	43·5	+31·6	59	297·3 246·0	260·1	51·3	+37·3	263·7	−5·3	−3·6
Leafield (S.)	C.W. 8·7	60	246·0 300·0	260·2	54·0	+39·8	60	300·0 247·0	260·6	53·0	+39·4	263·7	−3·5	−3·1
Moscow	Spk. 4·8	17	62·5 70·0	66·0	7·5	+ 4·0	16	70·0 64·8	66·3	5·2	+ 3·7	66·0	0·0	+0·3
Nantes	Spk. 2·6	18	192·0 207·0	202·1	15·0	−10·1	20	207·0 196·0	202·8	11·0	− 6·8	204·4	−2·3	−1·4
Nantes	Spk. 4·2	20	197·5 209·0	202·6	11·5	+ 6·4	28	209·0 194·0	200·9	15·0	+ 8·1	204·4	−1·8	−3·5
Nauen	C.W. 4·9	16	75·0 89·0	80·5	14·0	+ 8·5	12	87·5 75·0	80·8	12·5	+ 6·7	80·9	−0·4	−0·1
Nauen	C.W. 6·2	—	—	—	—	—	25	85·7 68·0	78·2	17·7	−10·2	80·9	−0·9	−2·7
Ongar	C.W. 2·9	51	240·0 252·0	245·6	12·0	+ 6·4	41	254·5 240·0	243·8	14·5	+10·7	246·0	−0·4	−2·2
Ongar	C.W. 3·8	15	225·0 250·5	242·2	25·5	−17·2	13	250·0 238·8	244·5	11·2	− 5·7	246·0	−3·8	−1·5
Ongar	C.W. 4·2	127	234·0 259·5	247·1	25·5	−13·1	118	261·0 234·2	245·6	26·8	+15·4	246·0	+1·1	−0·4
Paris	Spk. 2·6	53	167·5 171·0	169·6	3·5	− 2·1	48	170·7 170·0	170·3	0·7	+ 0·4	171·3	−1·7	−1·0
Stonehaven	C.W. 4·5	16	335·0 340·0	336·6	5·0	+ 3·4	—	—	—	—	—	336·9	−0·3	—

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The mean bearings on this station at night are identical with those by day, and the error referred to in (i) above is thus the same. Apart from this transmitting station, however, there is no essential difference between the variations and errors experienced on either damped or undamped waves.

It is not the purpose of the present paper to enter into a discussion of the magnitude, frequency, and possible causes of the variations of bearings experienced at night as this has been the subject of an investigation on a wide scale conducted by the Radio Research Board for some time past.

(iii) *Strength of Signals.*—The signals obtained on the above Bellini-Tosi set used as described were no stronger than those on the small portable Robinson coil set, using the same amplifying apparatus. An interchange of the latter, with the observers, failed to produce any difference in the regular receiving range of either set.

PART III. GENERAL DISCUSSION ON THE OPERATION OF THE THREE SYSTEMS

10. *Introductory*

THE experimental results obtained in Part II confirm the theory given in Part I, which shows that all three existing systems of direction-findings are fundamentally identical with a single-turn loop rotating about a vertical axis. Whatever distortion is produced in an arriving electromagnetic wave by geographical features, etc., and whatever may be the cause of the variations experienced both by day and night, all three systems are affected to the same degree. Before concluding the report it is thought that a general discussion on the operation of the three systems as derived from this investigation would be of interest.

Although by night the variable errors which are constantly present are very much larger than the possible errors of either instrument or observer, this is not true for general daylight working.

In the following remarks it should be understood that reference is made to the operation of direction-finders only on wave-lengths from 1·8 to 9·0 km. in length, either damped or continuous waves, these being the limits worked over in the preceding experiments. A similar comparison of the systems on shorter wave-lengths will be the subject of further investigation.

11. *Instrumental Errors*

The single frame coil is the nearest approach of the three systems to the theoretical ideal of a single-turn loop, comprising as it does a single oscillatory circuit tuned to resonance. By careful design, any error due to the shape and mode of winding of the coil can be reduced to a negligible quantity. Mutual induction between the frame and the amplifier circuits can be eliminated by situating the latter at a suitable distance below

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the former, and by paying attention to screening in a thorough manner. The most common error of a single frame is that arising from " antenna " effect, which can, however, be practically eliminated by the use of a compensating condenser as already described.

The Bellini-Tosi system with its large fixed loops employs a circuit which is the most complicated of the three systems, and accordingly has a greater liability to instrumental error. The two aerial systems have each to be oriented relative to the geographical meridian, and these with the remainder of their circuits have to be as identical as possible. To take full advantage of the large aerial loops employed, these must be very accurately tuned with condensers of similar power factor, an operation requiring some skill and time to carry out correctly. The existence of this balance is not always easily determinable, owing to the peculiar habit of the " buzzer test zeros " of wandering about, even when bearings on external stations remain quite steady. The construction of the radio-goniometer requires great care to obtain freedom from the possible errors which may arise. The elimination of mutual inductance between the search coil of the goniometer and the amplifier can be attained as with the single coil.

The circuit of the Robinson system is also somewhat more complicated than that of the single frame, but gives the advantage of the reception of an audible signal during the observation of bearings without swinging the coil. While any errors due to the shapes of the coils employed can be made practically negligible care is required in setting the two coils accurately perpendicular to have zero mutual inductance, although this is merely an initial adjustment. The arrangement of the receiving apparatus can be made very similar to that of the single frame set to avoid the introduction of errors.

12. *Errors of Operation and Observation*

The experiments made on the single-frame set described above showed that by the use of the compensating condenser the zeros of signal strength can be made very sharp, and bearings were frequently readable to within 0°·2, and sometimes to 0°·1. With adequate signal strength this adjustment and accuracy are maintained for the same wave-length adjustment. At this accuracy movement of the operator must be avoided, since he contributes to the " antenna " effect for which compensation is made. Owing to inadequate signal strength or more generally to interference, it was necessary to take swing observations, using angles of swing varying from 0°·2 to 6°·0. This action considerably decreases the accuracy, for it is not easy to limit the extremes of the swing to fractions of a degree, and the bearing obtained is usually a multiple of half a degree. In reference to this it may be noted that it is somewhat easier to note the limits of swing of a pointer moving over a fixed scale

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than a scale moving past a fixed division. With large diameter scales, however, this involves some considerable movement of the head of the observer. In either case, with quick swing readings over considerable angles, the possible errors of misreading the scale, particularly on the 5° and 10° divisions, are by no means negligible.

The possible errors due to mistuning of one of the aerials in the operation of the Bellini-Tosi set have already been mentioned. In using tuned aerials, quick searching on the same or a neighbouring wave-length is undoubtedly an advantage of this system, but exploring over a range of wave-lengths is practically impossible without the use of separate tuning condensers for each wave-length required. With untuned aerials, however, very rapid searching can be carried out over a large range of wave-lengths. Using either tuned or untuned aerials, with a centre earth connection in the latter case, it is rare that the "zeros" are so sharp as to permit of a reading to within 0°·5, and the bearings obtained on this system are generally multiples of 0°·5. Although the lightness of the search coil of the goniometer makes it very much easier to swing than a large frame, the possible errors due to swing readings are much the same. The degree divisions on the average goniometer scale are small, with the result that difficulty is sometimes experienced in taking quick readings. While any such error of reading would probably be detected immediately in observing a fixed transmitting station, this would not be the case in observing on a mobile station. The angles of swing used in the above experiments ranged from 4° to 40°, the larger angles being necessitated by either interference or weak signals.

With the Robinson system a great advantage is obtained over the other two, in that the whole rotating coil system is stationary during the operation of "swinging," for the equivalent coil of the set is effectively swung by the operation of the switch. The disadvantage that the angle of swing is fixed by the ratio of area turns of the two coils is not always serious. By using this method the reading can be made to the highest accuracy of the scale, about 0°·1. In taking a bearing two readings are usually made, being the limits of displacement of the coil to disturb the balance of signal strength in the telephones. These limits are usually separated by about 1° with average signals, and in the above experiments the "accuracies," which are half of this change in reading, ranged from 0°·2 to 2°·0. With such small movements of the scale and pointer, any misreading of the scale or errors in estimating the midway position are practically impossible, and the system is thus undoubtedly most useful for watching a station to observe small or large variations. With the modern sets employing a large ratio of the coils, the alleged 90° ambiguity of this system is entirely eliminated.

The actual zeros obtained with either the Bellini-Tosi or single-frame sets were noticeably sharper with heterodyned undamped

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waves than with damped waves, a point which is explained by Ballantine* as due to the greater sensitivity of a detector for undamped waves.

With the Robinson sets, however, it has been noticed that in spite of this increased sensitivity of the detector, the accuracy to which bearings may be observed on continuous waves is less than when receiving ordinary "spark" signals. This effect, however, does not prevent the accurate observation of bearings with the Robinson set to well within 1° on continuous waves.

GENERAL CONCLUSIONS

THE general result of this discussion thus shows that whereas each system may have its own sphere of action, there is essentially no difference in their basic principles. Permanent errors due to location and the variable errors by day and night are the same on each system, and the usual night errors are very much greater in magnitude than the limits of accuracy of either of the three systems. On a fixed wave-length the Bellini-Tosi system is the quickest to operate, and using untuned aerials this advantage is retained over a range of wave-lengths. Where extreme rapidity is not, however, necessary, the single frame would appear to be just as efficient. In the presence of large external noise, the Robinson system is claimed to be the best, but the present authors have as yet had no experience of this.

* S. BALLANTINE, The Radio Compass, *Year-book of Wireless Telegraphy and Telephony*, 1921, 1145.

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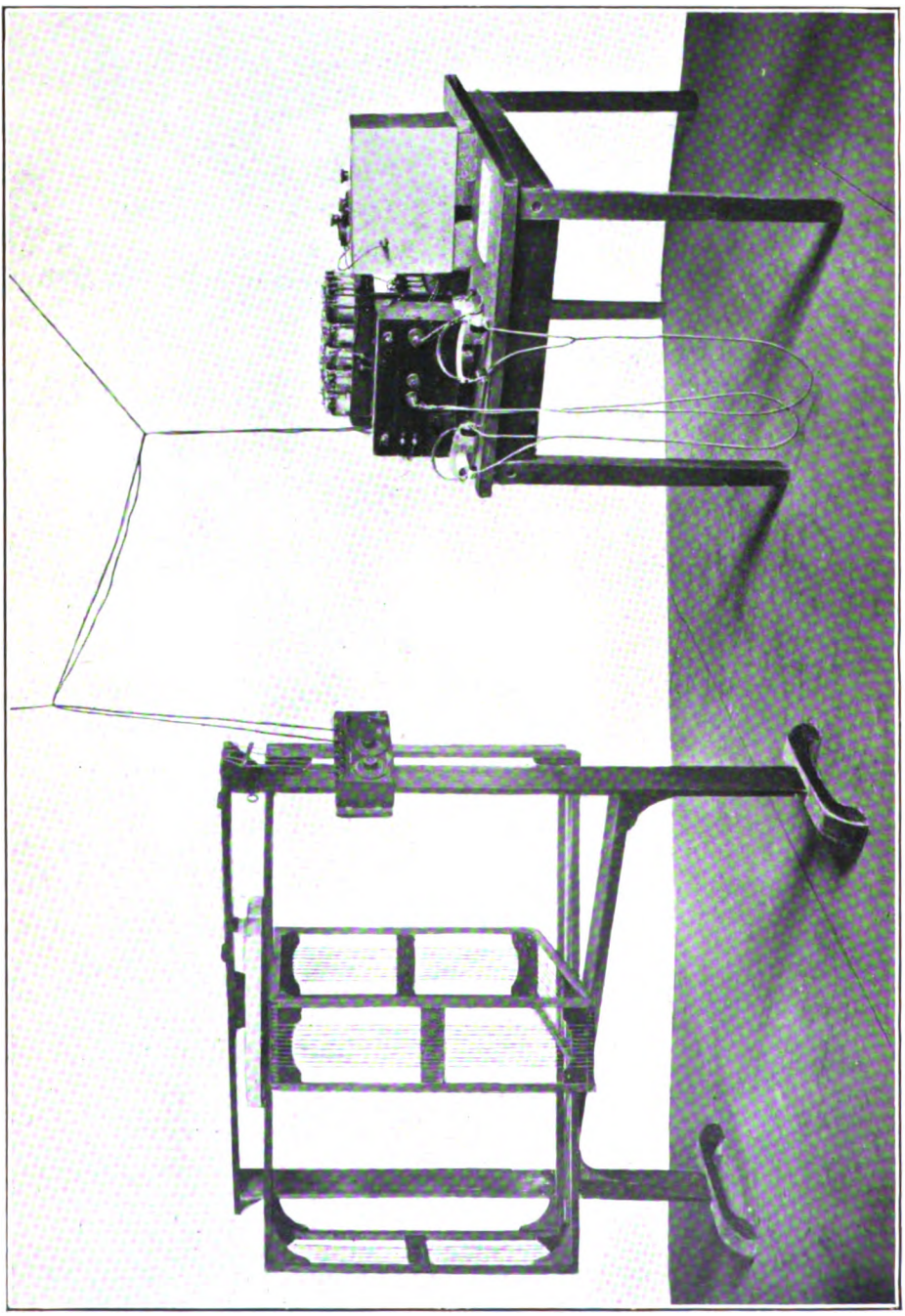

PHOTOGRAPH OF ONE OF THE DIRECTION-FINDING SETS EMPLOYED IN THIS INVESTIGATION.

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PART I—OBSERVATIONS ON FIXED STATIONS FEBRUARY, 1921—MARCH, 1922

By R. L. Smith-Rose, Ph.D., M.Sc., D.I.C., A.R.C.Sc., A.M.I.E.E.
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INTRODUCTORY NOTE

TOWARDS the end of 1920 it was decided to erect a number of directional radio receiving sets in various parts of the British Isles, attached either to Universities or Government experimental establishments. The object of these installations was to take regular observations of the apparent radio bearings of various transmitting stations, whose positions were accurately known, in order to obtain data on the nature, magnitude and other characteristics of the variations of bearings which had been previously known to take place. While the places for observations were originally selected to obtain two or more sites on great circles from certain land transmitting stations, the final choice was made more from the point of view of availability of both site and observer than from other considerations.

Under the direction of the Directional Wireless Committee of the Radio Research Board Dr. R. L. Smith-Rose undertook the personal supervision of this investigation throughout, from the inspection of the various sites, and erection of the apparatus down to the collection and co-ordination of the results obtained. For reasons of expediency and the immediate availability of suitable apparatus, the work was commenced by observations with the Robinson direction-finding system upon the European high-power "spark" transmitting stations operating on wave-lengths between 2,000 and 9,000 metres. An organisation of ten observing stations was set up in 1921, seven of these being located at British Universities. The location of these sets with other data concerning them follows this Introductory Note, and a detailed description of the installations is given in the Report. One of the direction-finding sets was erected at the National Physical Laboratory, Teddington, and was used chiefly as a control on the general organisation. All observers were set to work on a regular programme of observations extending over three to four hours per day. Modifications in this programme were made from time to time to meet changed conditions, all instructions being issued from the National Physical Laboratory where the results were forwarded weekly by the observers for the work of collation.

Regular observations were commenced at Teddington on 7th February, 1921, and this first Part of the Report deals with the progress of the investigation from that date until 4th March, 1922. During this period over 41,000 readings were received, and a very brief summary of these is given in tabular form. These results are further illustrated by numerous graphs, which are discussed in detail in connection with the deductions drawn therefrom.

Early in the second year of the investigation all the direction finders were equipped for reception of continuous waves, and the

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work was consequently extended to the European C.W. transmitting stations, still however being confined to the comparatively long waves in the range of 2,000 to 9,000 metres. The results of these observations continued during the second year of the investigation up to March, 1923, will be issued as Part II of the main Report.

Towards the end of 1922, the investigation was extended to much shorter wave-lengths, concentrating particularly upon the 450 metre wave, which is the one in general use for commercial direction-finding in this country at the present time. Owing to the fact that only low-power transmitting stations were in operation on these shorter waves, it was found necessary to alter somewhat the location of the direction-finders for suitable observations, and the advanced stage of development of the Bellini-Tosi system made its use desirable and expedient in this particular work. The collection of observations on these shorter wave-lengths was continued until 31st March, 1924, to obtain data on a somewhat similar scale to those published herewith, and the results of these observations will be contained in Part III of the Report.

In reviewing the results outlined in the present Part of the Report, in which the variations in the observed bearing are seen to attain quite large values under certain conditions, two points should be emphasised: first, that the stations upon whose transmissions observations were made were situated at considerable distances from the receivers—rarely less than 100 miles, and in some cases greater than 1,500 miles; second, that in the majority of cases the transmitted waves passed over considerable tracts of land during some portion of their path. In the extension of the work to the shorter waves, it has been possible to locate one of the observing stations on the coast, and to take readings of the apparent bearings of various ship transmitting stations, whose positions were known at the time. By this arrangement the transmitted waves passed entirely over sea, and it has already been found that under these conditions at distances up to the order of 60–100 miles, the radio direction-finding observations show a variation of only a few degrees, the individual bearings showing a maximum error of the order of 5°. Simultaneous observations taken on the same waves after they have travelled considerable distances over land show variations of the order of 60°, thus being comparable with those tabulated in the accompanying report. This aspect of the results should be emphasised as being of considerable importance in the application of radio direction-finding to marine navigation problems, where the majority of the work is carried out at comparatively short distances (less than 100 miles) and where the transmissions are nearly always entirely over sea.

Table No. 23 of this Part of the Report illustrates the great reduction in the extent of the variation at short distances even

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when the transmission is entirely overland and waves of moderate length are employed. At distances of 4·6 and 10 miles, the maximum error in observed bearings was 2·3°. Similarly, on the shorter wave-length of 450 metres, the variations observed in two instances of separate transmissions over distances of 10 and 15 miles overland, show a maximum error of the order of 1°. Further consideration of this matter and of the relative behaviour of long and short waves is left for the later Parts of the Report.

F. E. SMITH,
Chairman of the Committee on Directional Wireless.

October, 1924.

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Radio Direction-Finding Sets in Use

No.	Situation.	Responsible Authority.	Supervisor of observations.	Observers.	Duration of observations.
1	Aberdeen ..	The University	Prof. H. M. Macdonald, F.R.S.	J. E. Ritchie, M.A. J. Coull.	9th May, 1921, to 4th Mar., 1922.
2	Bangor	University College of North Wales.	Prof. E. Taylor-Jones, D.Sc.	R. D. Rowlands, B.Sc...	7th Feb., 1921, to 4th Mar., 1922.
3	Belfast	Municipal College of Technology.	Major R. Stanley, B.A. ..	J. Melia .. .. .. C. Wood.	1st Aug., 1921, to 4th Mar., 1922.
4	Bristol	The University	Prof. A. M. Tyndall, D.Sc.	M. G. Bennett, B.Sc. ..	7th Feb., 1921, to 4th Mar., 1922.
5	Cambridge ..	The University	E. V. Appleton, M.A., D.Sc.	W. T. Gibson, B.A. .. R. S. Barker.	11th April, 1921, to 4th Mar., 1922.
6	Leeds	The University	Prof. R. Whiddington, D.Sc.	G. Morton, B.Sc. ..	5th Mar. to 23rd July, 1921.
7	Newcastle ..	Armstrong College ..	Prof. G. W. Todd, D.Sc...	W. Faid, M.Sc. .. .. H. Oyston, M.Sc.	28th Feb., 1921, to 4th Mar., 1922.
8	Peterborough ..	P.O. Experimental Station	N. P. Hinton, B.Sc. ..	W. F. Lowe	26th Mar. to 12th Nov., 1921.
9	Slough	Radio Research Board Station.	R. L. Smith-Rose, Ph.D., M.Sc.	S. R. Chapman, B.Sc. ..	9th Jan. to 4th Mar., 1922.
10	Teddington ..	National Physical Laboratory.	R. L. Smith-Rose, Ph.D., M.Sc.	R. L. Smith-Rose, Ph.D., M.Sc. A. C. Haxton.	7th Feb., 1921, to 4th Mar., 1922.

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VARIATIONS OF APPARENT BEARINGS OF RADIO TRANSMITTING STATIONS

PART I—OBSERVATIONS ON FIXED STATIONS FEBRUARY, 1921–MARCH, 1922

SECTION I.—DESCRIPTION OF INSTALLATIONS AND OF EXPERIMENTS ON INSTRUMENTAL AND LOCAL ERRORS

(1) *Detailed description of the Installations*

AS being generally suitable for the investigation from the point of view of accuracy, simplicity and economy, the Robinson system [1]* was employed, and a particular design of this was standardised, the details being as follows. The "auxiliary" or A coil was a light wooden frame-work of size 5′ by 3′ wound with 30 turns of No. 18 S.W.G. copper wire. The "main" coil B was similarly constructed of size 3′ by 2′ 10″, and wound with 16 turns of the same size wire, the depth of the winding in each coil being 8″.The two coils screwed together at right angles were arranged to revolve in a stand about 6′ high, the bottom of the coils being thus about 2′ 6″ above the ground.

The four leads from these coils were brought out at the top of the stand and connected to the terminals of the combined tuner switch-box, fixed at the side of the stand. This contained :—

(1) A condenser continuously variable up to about 0·008 microfarad, being suitable to tune the coil system for the range of wave-lengths from 2,000 to 9,000 metres.
(2) A commutator switch for the reversal of the connections of the coil A ; and
(3) A switch enabling coil A to be disconnected from the circuit and a small coil substituted, accurately balanced to have the same self-inductance, but to be practically non-receptive to external signals.

This switch permitted of the preliminary setting of coil B in approximately the maximum position without disturbing the tuning of the circuit, prior to the introduction of A and the accurate determination of the bearing by operation of the reversing switch. A circular wooden scale 2′ in diameter was fixed to coil A, the direction of which was read from a sight on the stand.

The entire apparatus at each station was exactly identical, and was erected in as similar a manner as possible to reduce to the minimum all possible instrumental errors. Every endeavour was made to obtain at each place a suitable site on flat open ground, free from trees, metal-work and overhead wires, etc., but in some cases where an ideal site was not available, a compromise had to be made.

* These numbers refer to the Bibliography on p. 93.

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For the housing of the sets, wooden huts were erected of size 16′ by 10′ by 8′ high, designed with a view to eliminating all unnecessary metal-work, and erected with the longer side of the hut in the geographical meridian at each place. The Robinson receiving set was then placed in the centre of this hut with the frame in the N and S direction. The orientation of each set was carried out with a good prismatic compass, which could be read to 0·1°, and with due correction for the compass error and the magnetic variation at each locality, the coil system was arranged so that, with the " main " or B coil in the geographical meridian, the scale reading on the direction-finder was 0° or 180°. The compass was sighted on the edge of the frame-work of the coils and the mean was taken of the readings on the two sides of each coil. It is considered that by this means the setting of the coils was accurate to within 0·25°, and in this position the stand was securely screwed down to the floor of the hut by means of brass angle plates. The setting of the coils at each station was later checked from the sun by a simple " shadow " experiment carried out at noon for each locality. In all cases, the first setting was found to be accurate to well within 0·25°.

The leads from the tuner switch-box were taken to the terminals of a standard form of 7-valve transformer-coupled amplifier giving three stages of amplification at radio-frequency, and rectification followed by three-stage amplification at audio-frequency. The batteries associated with this amplifier were (*a*) a 6-volt accumulator for the lighting of the valve filaments, and (*b*) a 70-volt battery consisting of 50 Leclanché cells for the anode current supply. Both amplifier and batteries were insulated on paraffin blocks, and mounted on a table in a corner of the hut, about 5′ away from the receiving coils, the telephone cords being long enough to allow the observer easily to manipulate the set when standing near the tuner box. A view of the entire installation including the screened local oscillator which was introduced later, is shown in the frontispiece.

(2) *Scope of investigation*

Although the chief object of the investigation was to collect data on the variable errors of direction-finders, much useful information has also been obtained about the errors which may, or may not, be of a permanent nature, and which are due to the locality of the installations. In order to distinguish the smaller errors due to the site from those inherent in the instruments it was considered advantageous to carry out some experiments upon the limits of accuracy of the latter under the conditions of use.

(3) *Instrumental Errors of the Direction-Finding Installations*

A somewhat detailed study of the instrumental errors of the Robinson system of direction-finding has been described in a paper by Hollingworth [2]. Although this discussion is largely

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theoretical, it is supported by the results of actual experience which tend to show that such errors never amount to more than 1° in the apparent observed bearing, and are usually much smaller than this. Owing to the large errors ranging up to 40° or 50° experienced with direction-finders as a whole from other causes, the more minute instrumental errors have not been investigated in great detail, but various experiments have been carried out to ascertain the probable limits of accuracy of the particular receiving sets in use. In the consideration of the results it should be remembered that the particular instruments used were not intended for accuracies of less than 1°, and the experiments were actually carried out to verify that this limit was justifiable in collating the results of the general investigation.

(*a*) *Scale Calibration.*—Under this heading is included any possible error which might be due to the scale and its graduation, quite apart from any wireless effect. In the type of instrument used, the scale consisted of a vertical strip of thick paper pasted on to the outside edge of a circular wooden hoop 2′ in diameter. This hoop was fixed at four points to the large coil, concentric with the axis of rotation. The paper scale was divided equally into 360° the width of a degree division being about one-fifth of an inch. A fine line drawn on a piece of transparent celluloid mounted vertically at about one-eighth of an inch from the scale served as an indicator, parallax being avoided by sighting through a circular aperture fixed about 1′ away at a convenient height for the observer's eye. By this arrangement the reading of the indicating line on the scale could be easily estimated to a tenth of a degree.

The possible errors which can arise from such a type of scale include the expansion or contraction of the paper after graduation, the warping of the wooden hoop resulting in its being non-circular, and the eccentricity of the hoop on the axis. To gain a knowledge of the order to which these combined errors could amount, the scales of two similar instruments were tested against a geometrically constructed protractor divided into 15° sectors. This was mounted concentrically on the axis of the coils, and rested flat on the upper edge of the scale. Choosing one radial line on the protractor as a zero, and superposing this on the zero of the scale, the readings of each of the 15° radii were observed on the scale to 0·1°. The difference in the readings at every 15° gives the algebraic sum of the errors of both scale and protractor. To eliminate the protractor error the above readings were repeated with the scale zero set at the 15°, 30°, etc., divisions on the protractor. By this means a set of 24 readings is obtained for each 15° division of the scale and the mean of these 24 readings will be independent of any error of division of the protractor.

Tests made in this manner on two sample scales showed that while over some portions of the scales the error of calibration was less than a tenth of a degree, over other portions of the scale the error amounted to as much as 0·5°. The calibration curves show

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that a difference of as much as 0·6° might occur in taking direct and reciprocal observations of bearings at some points on the scale.

(*b*) *Reversed Coil Tests.*—One instrumental error to which closed loop and coil aerials are subjected is known to direction-finder experimenters as " vertical " or " antenna effect." This is the result of associating the tuned receiver circuit of the direction-finder directly with the first valve of the cascade amplifier. Owing to the comparatively large bulk of the batteries connected to the valve filament, there will be very appreciable capacity between this point and earth ; whereas the grid, being a small wire spiral and highly insulated, will have a very small capacity to earth.

The presence of these capacities will result in a vertical current to earth flowing on either side of the main tuning condenser under the influence of the E.M.F.'s induced in the two sides of the coil by the incoming waves. The inequality of these " vertical " or " antenna " currents will result in a residual potential difference across the main condenser, and so will be effective in producing a signal in the receiver.

This " antenna effect " is chiefly noticeable in rendering the zero of signal very indistinct, making its exact determination somewhat difficult. In certain conditions also, " antenna effect " displaces the minimum of the coil from its true setting and since the effect is non-directional, the displacement is of the opposite sign when the coil is rotated through 180°. The existence of this " antenna effect " can thus frequently be detected on directional receiving systems by taking direct and reciprocal readings, when the difference of these less 180° will represent twice the error due to the effect.

In the Robinson system, the rotating coils are not operated directly on a minimum, but with a swing of an equivalent coil through about 30°, as has been described elsewhere [3]. It is therefore to be thought that the effect will not materially contribute to an error in reading.

Another non-directional effect which, being somewhat similar, may be linked with the true antenna effect is that due to the direct pick-up of the leads from coil to amplifier, and due to the leads and transformers of the amplifier itself.

To gain a definite knowledge of the magnitude of the errors which might be introduced by these effects, a large number of experiments was carried out on the various sets in use, taking duplicate bearings on various transmitting stations with the coil system first in the normal and then in the reversed position. By the " normal " position is understood that setting of the coil system in which the scale reading is approximately the true bearing of the transmitting station.

The following Table 1 shows a summary of the observations which were carried out on coil reversals on the different sets over a period of four successive weeks. In all cases the readings were taken in the daytime and the pairs of normal and reversed readings were taken as quickly as possible to avoid any external

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variation which might occur between the readings. By taking a number of pairs of readings the effect of such variations and also of observational error is minimised.

TABLE 1.—SHOWING RESULTS OBTAINED FROM OBSERVATIONS ON COIL REVERSAL

Receiving station.	Transmitting station.	Wave-length.	No. of observations.	Mean normal bearing—A.	Mean reversed bearing—B.	Difference (B ± 180)—A.	Correction for normal bearing.
		(km.)		(deg.)	(deg.)	(deg.)	(deg.)
Aberdeen .. (Set 1)	Paris ..	2·5 Spk.	6	161·1	340·6	−0·5	−0·3
	Poldhu ..	2·8 ,,	10	184·0	3·4	−0·6	−0·3
	Paris ..	3·2 ,,	10	162·2	341·5	−0·7	−0·3
	Nauen ..	3·9 ,,	6	126·4	305·2	−1·2	−0·6
Bangor .. (Set 2)	Horsea ..	2·5 C.W.	4	135·1	321·1	+6·0	+3·0
	Paris ..	2·5 Spk.	16	132·5	311·0	−1·5	−0·7
	Poldhu ..	2·8 ,,	4	195·9	16·0	+0·1	+0·1
	Cleethorpes	3·0 ,,	2	71·0	253·0	+2·0	+1·0
	Paris ..	3·2 ,,	22	135·1	315·3	+0·2	+0·1
	Nauen ..	3·9 ,,	20	79·1	263·3	+4·2	+2·1
	Horsea ..	4·0 C.W.	12	138·4	318·8	+0·4	+0·2
	Horsea ..	4·5 C.W.	16	141·2	319·3	−1·9	−0·9
Bristol .. (Set 4)	Paris ..	2·5 Spk.	100	127·9	307·9	0·0	0·0
	Poldhu ..	2·8 ,,	32	230·2	49·2	−1·0	−0·5
	Cleethorpes	3·0 ,,	4	36·3	216·3	0·0	0·0
	Paris ..	3·2 ,,	52	127·0	307·9	+0·9	+0·5
	Aranjuez ..	3·5 ,,	4	186·0	6·0	0·0	0·0
	Chelmsford	3·8 C.W.	18	78·3	258·2	−0·1	−0·1
	Coltano ..	3·9 Spk.	4	124·0	304·0	0·0	0·0
	Nauen ..	3·9 ,,	12	75·0	255·1	+0·1	+0·1
	Nantes ..	4·0 ,,	4	174·2	354·2	0·0	0·0
	Horsea ..	4·5 C.W.	24	121·1	301·2	−0·1	−0·1
	Cleethorpes	4·6 Spk.	4	40·0	220·0	0·0	0·0
Newcastle .. (Set 7)	Paris ..	2·5 Spk.	60	155·2	354·9	−0·3	−0·1
	Poldhu ..	2·8 ,,	16	205·7	27·2	+1·5	+0·7
	Aberdeen ..	3·0 C.W.	5	352·2	171·0	−1·2	−0·6
	Cleethorpes	3·0 Spk.	3	145·6	327·6	+2·0	+1·0
	Paris ..	3·2 ,,	22	157·1	335·9	−1·2	−0·6
	Chelmsford	3·8 C.W.	3	157·0	337·0	0·0	0·0
	Nauen ..	3·9 Spk.	17	96·3	277·3	+1·0	+0·5
	Karlsborg ..	4·2 ,,	7	61·9	241·0	−0·9	−0·5
	Horsea ..	4·5 C.W.	21	175·8	356·7	+0·9	+0·5
	Cleethorpes	4·6 C.W.	10	146·6	328·3	+1·7	+0·9
	Moscow ..	5·0 Spk.	2	71·4	251·3	−0·1	−0·1
	Clifden ..	6·0 C.W.	8	255·0	77·3	+2·3	+1·1
Peterborough .. (Set 8)	Paris ..	2·5 Spk.	20	157·1	336·7	−0·4	−0·2
	Poldhu ..	2·8 ,,	7	233·1	53·2	−0·1	−0·1
	Chelmsford	3·8 ,,	8	155·5	335·5	0·0	0·0
Teddington .. (Set 10)	Warsaw ..	2·1 Spk.	6	79·3	258·2	−0·9	−0·5
	Paris ..	2·5 ,,	10	145·7	344·8	−0·9	−0·5
	Poldhu ..	2·8 ,,	30	249·8	70·5	+0·7	+0·3
	Budapest ..	3·0 ,,	10	100·5	280·3	−0·2	−0·1
	Paris ..	3·2 ,,	8	145·1	324·5	−0·6	−0·3
	Chelmsford	3·8 C.W.	12	57·7	237·8	+0·1	+0·1
	Moscow ..	5·0 Spk.	16	66·3	245·5	−0·8	−0·4
	Clifden ..	5·8 ,,	8	294·6	115·7	+1·1	+0·5

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TABLE 2.—SHOWING ANALYSIS OF ERROR IN OBSERVED BEARINGS ON SET NO. 10, NOT DUE TO CALIBRATION OF SCALE

Transmitting Station.	Wave-length.	Normal reading.	Observed difference of readings on reversal. C.	Difference of readings on reversal due to scale error. D.	Error in bearing not due to scale error. $\frac{C-D}{2}$
	(km.)	(degrees)	(degrees)	(degrees)	(degrees)
Warsaw ..	2·1	79·3	− 0·9	− 0·5	− 0·2
Paris	2·5	145·7	− 0·9	0·0	− 0·5
Poldhu ..	2·8	249·8	+ 0·7	+ 0·5	+ 0·1
Budapest ..	3·0	100·5	− 0·2	− 0·4	+ 0·1
Paris	3·2	145·1	− 0·6	0·0	− 0·3
Chelmsford ..	3·8	57·7	+ 0·1	− 0·6	+ 0·3
Moscow ..	5·0	66·3	− 0·8	− 0·5	− 0·1
Clifden ..	5·8	294·6	+ 1·1	+ 0·3	+ 0·4

When taking observations with coil reversal in this manner, the actual readings obtained include any errors due to the scale as well as those due to antenna effect which may be shown up by this procedure. As mentioned above, however, only two of the sets in use were tested for scale accuracy.

Table 2 above shows a comparison for Set No. 10 between the errors obtained from Table 1 and those obtained for the scale calibration for this set. It will be seen from this table that while, in some cases, the scale error partly accounts for the difference in readings obtained on reversal, in others this difference is unaffected or even augmented by correction for the scale. The last column in Table 2 shows the actual error in the observation of the bearing of a station with the coil in the normal position, as exhibited by these coil reversal experiments. It will be seen that the maximum error thus obtained over the range observed is 0·5°, while the error is in general much less than this. While the error obtained on Paris decreases when the wave-length is increased, as would be expected from theoretical considerations, there is no consistent variation with wave-length for the other transmitting stations observed. This may have been due to other conditions, such as the difference in form of the waves from different stations, which may have a greater effect than the alteration in frequency.

Reverting now to Table 1, it is seen that, for the receiving sets 1, 4, 7 and 8, the error in the normal bearing as shown by the coil reversal experiments has a maximum value of 1·1°, while the usual value is about 0·5°. As experienced above, the scale error for these latter sets cannot wholly account for this, although it may partially do so. For example, at Set 7, Moscow and Clifden are nearly 180° apart, and so any scale error should be

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numerically the same for these two stations. It is seen, however, that the observed errors differ by 1°. Again, the two wave-lengths of Paris always give a different error, although there can, of course, be no question of difference of scale errors in this case. It is to be noted also that, for Sets 4 and 7, the error was greater for the long than for the short wave of Paris in contradiction to the results on the other sets.

The receiving set No. 4 is situated at the top of a stone tower, some 60 ft. above the ground, and it would be supposed that the antenna effect would be much reduced in such a position. It is, therefore, probably very significant that the errors given by the results in Table 1 should generally be negligible for this set, and in any case they have a maximum value of 0·5°.

The results obtained on Set No. 2 and recorded in Table 1 show that the errors are here abnormally increased, particularly in the case of transmission from Horsea and Nauen, when the error ranges up to 3°. This is probably due to some local conditions at this set, as other abnormal results have been obtained here which cannot be ascribed to any fault of the instrument, and it was previously expected that the site would not be entirely suitable for direction finding.

For example, large permanent errors ranging up to several degrees are obtained here on certain transmitting stations. Also the observed bearing changes considerably with change in wave-length at the transmitting station, *e.g.*, Paris and Horsea, giving changes of 2·3° and 6·1° respectively. In the case of the latter station, by applying the correction given in the last column of Table 1, the normal bearings so obtained are much more nearly the same for the three wave-lengths on which Horsea was observed.

Owing to the peculiarities exhibited by this set, many experiments were carried out by the author, which will be mentioned in appropriate places throughout this paper. In connection with the present experiments on " antenna effect," it was found that all the changes which were obtained by coil reversal could be produced by merely reversing the connecting leads at either tuner box or amplifier. This is, of course, to be expected, for such reversal of leads will naturally reverse the antenna effects due to capacity to the ground, and these experiments thus confirm the experience of an abnormally increased " vertical " effect at this particular station.

(*c*) *Detuning of the coil system.*—The correct condition of the direction finder for the observation of bearings is with the receiving coil accurately tuned to the length of the incoming waves by means of the variable condenser. This is a natural operation, since it ensures the maximum signal strength in the receiver. Unless otherwise stated, therefore, it is to be understood that all observations are taken with the coil tuned as accurately as possible. The effect of slightly detuning the coil system would be to change the phase relationship of the pure coil current and its resulting signal at the receiver. For example, it

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would be expected that the detuning would cause a misphasing of the coil and antenna effects, with a consequent reduction in the relative magnitude of the latter.

To gain some knowledge of the above effect, some experiments were carried out on the various sets, taking observations with the coil tuned and detuned. The detuning was carried out by alteration of the variable condenser by amounts corresponding to 10 per cent. and 20 per cent. changes in capacity, first in an increasing and then in a decreasing direction. Table 3 below shows a summary of the observations obtained.

TABLE 3.—VARIATION IN THE OBSERVED BEARINGS BY DETUNING THE RECEIVING COIL

Receiving station.	Transmitting station.	Wave length (λ). km.	Mean observed bearings (degrees).					Mean change produced by detuning (degrees).	
			Condenser tuned.	Condenser detuned.					
				+10%	+20%	−10%	−20%	+	−
Set 1 ..	Paris ..	2·5	162·0	161·7	—	162·1	—	−0·3	+0·1
	Paris ..	3·2	161·8	161·8	—	161·9	—	0·0	+0·1
Set 2 ..	Paris ..	2·5	132·2	131·0	131·2	133·0	132·4	−1·2	+0·8
	Poldhu ..	2·8	196·3	196·8	196·5	196·1	196·0	+0·6	−0·6
	Nantes ..	2·8	169·0	169·5	—	171·1	—	+0·5	+2·1
	Paris ..	3·2	134·9	135·3	135·4	134·7	134·7	+0·5	−0·2
	Nauen ..	3·9	75·3	75·6	—	75·0	—	+0·3	−0·3
	Coltano ..	4·2	126·2	125·8	—	126·5	—	−0·4	+0·3
	Karlsborg	4·2	51·2	50·7	—	51·4	—	−0·5	+0·2
	Nantes ..	4·5	167·9	168·0	—	167·7	—	+0·1	−0·2
Set 4 ..	Paris ..	2·5	127·9	128·0	128·0	127·0	127·0	+0·1	−0·9
	Poldhu ..	2·8	231·0	231·2	231·0	230·6	230·7	+0·2	−0·4
	Paris ..	3·2	126·6	126·6	126·6	126·7	126·4	0·0	−0·2
	Nauen ..	3·9	75·0	75·7	—	75·1	—	+0·7	+0·1
	Horsea ..	4·5	119·8	119·8	120·1	119·7	120·1	+0·3	+0·3
Set 7 ..	Paris ..	2·5	154·8	155·1	155·1	154·7	154·4	+0·3	−0·4
	Poldhu ..	2·8	205·5	205·6	205·8	205·4	205·3	+0·2	−0·2
	Paris ..	3·2	156·2	156·4	156·5	156·0	155·6	+0·3	−0·6
	Nauen ..	3·9	97·5	97·8	98·0	97·0	97·4	+0·5	−0·5
	Horsea ..	4·5	174·1	173·0	—	172·2	—	−1·1	−1·9
Set 8 ..	Paris ..	2·5	157·2	157·2	157·2	157·2	157·2	0·0	0·0
	Poldhu ..	2·8	233·2	233·3	233·1	233·1	233·2	+0·1	−0·1
	Paris ..	3·2	158·0	158·0	158·0	157·9	158·0	0·0	−0·1
	Horsea ..	4·5	197·1	197·1	197·3	—	—	+0·2	—

The number of transmitting stations upon which these observations could be made was limited; first, because the loss of signal strength in some stations on detuning made an accurate observation difficult or even impossible, and, secondly, because a number of stations had only a short time of transmission. To carry out carefully a complete set of observations with the coil

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tuned and detuned takes three or four minutes, and it is necessary to return constantly to the tuned position to ascertain that the normal observed bearing has not altered from causes external to the instrument. Each of the above results, however, is the mean of several observations made at intervals over a period of four weeks, and all the readings were obtained in daylight. The tabulated results thus serve to indicate the effect of detuning a closed coil direction finder on the apparent bearings given by the latter.

These results show that while, in some cases, the change in bearing produced by detuning is negligible, in many cases the change produced is very appreciable and well exceeds the errors of observation. The extreme cases are shown by the observations on Nantes and Horsea at Sets Nos. 2 and 7 respectively, when a total change of as much as 2° may be produced by adjusting the condenser to one or other side of the true resonant value. In general the changes due to mistuning are greater than those due to coil reversal, but it is perhaps significant that the comparative errors from the two experiments are greatest for the same sets.

While the exact explanation of these results is somewhat obscure, they are to be expected as the effects of misphasing the pure coil signal E.M.F. relative to the signals produced by other effects such as the direct pick-up of the leads to the amplifier, and the displacement currents due to the capacity between the turns of the coil. The latter effect would be reversed when the coil is rotated through 180° and so would not be shown by the previous experiments.

That the direct pick-up of the leads of such a receiving set as that used is by no means negligible is easily demonstrated. With the seven-valve amplifier employed, signals from the more powerful spark transmitting stations such as Paris and Nauen can be received quite well at distances of 200 to 300 miles, by merely touching the grid terminal of the amplifier with the finger or by connecting two or three feet of wire thereto; for the human body or lead acts as an aerial, which, although untuned, picks up enough energy to give good signals in the telephones. When the receiving set is still nearer the transmitting station, even this "aerial" is unnecessary, the amplifier connections and transformers serving quite well to pick up the necessary signals. For example, Set 2 (Bangor) was situated at 9·7 miles from the Carnarvon transmitting station, employing 200 kilowatts for transatlantic communication. Signals were easily audible at this distance with only one or two valves, no other leads or circuits being necessary.

In this case some curious freak effects were observed at the receiver. The Carnarvon station employed at that time the "timed-spark" system of transmission, giving approximately

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continuous waves of length 14·4 kilometres. At the distance of the receiver (9·7 miles) and thus within about one wave-length of the radiating aerial, good "spark" signals were obtained with the receiving coil tuned to any wave-length from 2·0 to 10 km., but a distinct peak was noticeable at about 2·7 km., corresponding apparently to the sixth harmonic of the transmitted wave. When the receiver was adjusted to this harmonic, large changes in apparent bearing were given by this set from day to day, which were at first not understood. The explanation was found later in that these were due to slight errors in tuning adjustment, and, on carrying out some detuning experiments, the change in apparent bearing obtained was as shown in Fig. 2 (p. 44).

Owing to the conversion of the Carnarvon transmitting station to a pure continuous-wave system, further experiments on the observed effect were impossible, and while the explanation is somewhat obscure, it undoubtedly lies in the short distance between the transmitter and receiver, and the fact that the latter is under the influence of the direct inductive field from both the vertical and horizontal portions of the transmitting aerial. The whole principle of direction-finding assumes that the inductive field is negligible compared with the radiation field, and it would, therefore, be unwise to use a directional receiving set at such a short distance as one wave-length from the transmitter. Moreover, it should be remembered that the above observations were made upon what was either a sixth harmonic of the fundamental wave, or even possibly a normal mode of oscillation of the antenna.

In normal circumstances, however, it is seen that the mistuning of a closed coil direction-finder may give errors of bearing as great as 2°, and this result emphasises the necessity of accurately tuning the receiving coil before commencing the observation of a bearing.

(*d*) *Coil shape effect.*—A brief discussion of the possible errors which may be introduced by the mode of winding the direction-finding coil was given in an earlier Report of the Board [3].

(*e*) *Errors due to Unscreened Local Oscillators.*—In using a directional wireless system for the reception of continuous waves, it is desirable to work on the heterodyne principle, and to introduce at some point in the system local oscillations to give an audible beat note with the incoming oscillations. The resulting signal note in the telephones depends upon the relative amplitudes of the two sets of oscillations received. Since in direction-finding it is necessary to determine the conditions for some definite amplitude (sometimes zero) of the incoming oscillations, it is essential to maintain the constancy of amplitude of the local oscillations introduced into the system. In the case of the single-coil direction-finder this is easily done by mounting the

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local oscillator on the axis of the coil and adjusting its coupling with the coil to give a suitable value of the induced local oscillations. Alternatively, the local oscillator may be coupled on to some convenient point of the receiving amplifier, providing suitable precautions are taken to prevent any change in amplitude of the local oscillations arising from stray coupling between the oscillator and the rotating coil.

In the case of the crossed-coil system the difficulty is somewhat enhanced. The effective E.M.F. of the local oscillations at the amplifier terminals is the sum of the E.M.F.'s induced into each of the crossed coils. Since the connections of one coil are reversed in determining directions, one of these E.M.F.'s will be reversed, and thus the effective amplitude of the signal E.M.F. will vary as the commutating switch is operated. This can be obviated by arranging that the induced E.M.F. in one coil is zero; for instance, by mounting the oscillator inside the coil system and suitably orienting with respect to the two coils. The condition is, however, only partly satisfied in this way, owing to capacity coupling between coils and oscillator, and owing to the effect of the equivalent turns of box-coils mentioned above. Even if the condition is fulfilled, the arrangement is not satisfactory, owing to the difficulty of controlling the amplitude of the local oscillations introduced. It is usually found that even the feeblest triode oscillator with such a coupling gives much too great a strength of local oscillation for the best reception of signals.

The alternative thus remains of removing the local oscillator and so screening it that no stray field is effective at the coil system, the oscillations being introduced direct to the amplifier through a small astatic coupling under complete control. The author has shown that the problem of completely screening a small valve set generating radio-frequency oscillations is by no means an easy one, but can be solved by taking suitable precautions. In the paper [4] describing this experimental investigation, details are given of a suitable screened oscillator designed and used for direction-finding work; and this type of local oscillator has been used at all the direction-finding installations set up for the Radio Research Board in the extension of the experiments from "spark" to continuous wave working.

To illustrate the effect of the stray field from the oscillator in producing an error in bearing, the following results may be given, from an experiment made on the "unscreening" of the oscillator. At Teddington the transmissions from Chelmsford could be heard quite well on an ordinary spark receiver, owing to the impurity of the continuous waves employed. This enables observations of bearings to be made on this station both with and without the use of a local heterodyne, thus enabling any error due to the latter to be detected. A long series of experiments showed that with the screened oscillator placed at a distance of 4′ or 5′ from the coil, the error in observed bearing introduced by the operation

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of the oscillator is never greater than 0·1°, which is well within the limits of accuracy of observation. The screening box is provided with two lids, and the effect of removing these is shown in the following results :—

Condition of screened oscillator.	Chelmsford C.W. $\lambda = 3{\cdot}8$ km.	
	Observed bearing.	Error observed.
	(degrees)	(degrees)
Not in operation	57·3	—
In operation, fully screened	57·2	− 0·1
,, outer lid removed	61·5	+ 4·2
,, both lids removed	65·5	+ 8·2

While these results are only typical of the effect produced, and do not necessarily represent the greatest possibilities, they serve to show that an error of several degrees may be introduced in a direction-finding system by a local oscillator which is not efficiently screened.

(*f*) *Induction or re-radiation from the amplifier.*—Under this heading is included any errors in the apparent bearing which may arise due to the effect of the amplifier transformers or any of the associated leads in inducing a secondary E.M.F. into the coil system. The leads from coils to amplifier must, of course, be included in such an effect, but the amplifier transformers will probably be of more importance than these owing to their shape and to the fact that the signals will be amplified by one or more valves before reaching them. To minimise the possibility of the error, the amplifier was always mounted about 6′ away from the centre of the coil system, this being a convenient distance to which the operator's telephone cord would reach and also enabling him to control both tuner box, coil system and amplifier, without excessive walking to and fro. The leads from the tuner box to the amplifier, while not closely twined on account of the large capacity between them, were kept loosely twisted to avoid any loops which might have coupling with the coils.

To ascertain the magnitude of the error introduced in a system arranged thus, due to the above effects, some experiments were carried out on Set 10 at Teddington. The experiments consisted in carefully screening the whole of the receiving amplifier with its associated filament and anode batteries. The screen was formed of a large box of tinned iron sheet, about 0·032″ thick, and provided with a well-fitting lid overlapping three or four inches. All joints were carefully soldered over, two small holes only being used for entry of the leads from the tuner box, and for the bringing out of the telephone cord. Such a box had been

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found in the experiments on screening mentioned in the last section to be very effective at radio frequencies, and could only be made more perfect by metallically sealing on the lid. Daily observations were made with this screening box in position on various transmitting stations over a period of two weeks, and the results were compared with exactly similar observations taken over a period of ten days before and after this period with the screening box removed. A large number of readings were taken in the course of the experiment, and a summary of these taken in the daytime is given below in Table 4.

TABLE 4.—OBSERVATIONS OF BEARINGS MADE TO SHOW THE EFFECT OF SCREENING AMPLIFIER AND BATTERIES

Transmitting Station.	Wave-length.	Without screening box.		With screening box.		Difference due to screening.
		No. of observations.	Mean observed bearing.	No. of observations.	Mean observed bearing.	
	(km.)		(deg.)		(deg.)	(deg.)
Budapest ..	3·0	20	99·0	6	98·7	− 0·3
Chelmsford ..	3·8	95	57·7	46	57·4	− 0·3
Coltano ..	4·2	30	132·0	3	132·0	0·0
Paris (UFP) ..	2·4	69	145·0	37	144·8	− 0·2
Nauen	3·9	11	77·3	12	76·3	− 1·0
Paris (FL) ..	2·6	118	145·0	72	145·0	0·0
Paris (FL) ..	3·2	10	144·5	14	144·4	− 0·1
Poldhu	2·8	7	249·2	30	249·4	+ 0·2

It will be seen from this Table that usually the effect of introducing the screen is small, though quite definite; but in one case the resultant change in apparent bearing was as much as 1°. The corresponding readings taken at night show such large variations among themselves due to causes external to the receiver that the small changes due to the screening are completely masked.

Since, however, the above Table indicates the means of several sets of daily observations, the results given will be practically independent of small errors of observation.

While part of the small difference given above may be due merely to the presence of the metal box near the coils, some experiments to be described later show that the effect of the box only becomes appreciable when placed within 4′ of the coil. In particular, the error of 1° obtained on Nauen could not be accounted for in this way.

These results show, therefore, that where a direction-finder is required to give bearings accurate to within less than 1°, it is essential to screen as completely as possible the receiving amplifier and its associated batteries. Alternatively, the reactive effect

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of the amplifier transformers will be reduced by removing the amplifier to a greater distance from the coil than has been adopted, but this will increase the length of the necessary leads and the error due to their direct " pick-up " effect.

(*g*) *Operator's errors.*—The observers obtained at the various installations were usually post-graduate students or junior members of the staff of the University, the Professor of Physics undertaking the general supervision of the observations at each station.

As far as possible one observer carried out the observations over the whole period, but in a few cases two observers shared the duties. In either case the observers at each set remained unchanged for long periods, and it was found that, with good experience and practice, no personal error could be detected between the different observers.

The general result of the work, however, has been that, with two observers of equal experience at this particular direction-finding work, the personal error is *nil*. On consideration of the method of observation, it will be appreciated that this is the result to be expected. For the chief difference between two persons on a method employing aural reception concerns the inequality in the sensitivity of their ears. In the present work, no measurements are made which depend upon the absolute sensitivity of the ear, but only upon the ability of the ear to distinguish a *change* in intensity of the note received. It would be expected, therefore, that while the angle of the balance over which no change in intensity can be perceived might vary with different observers, the actual mean position indicating the direction required would be unaltered. This is exactly the experience of the author in the practical working of direction-finding sets. An observer entirely new to the work can obtain a fairly correct bearing, but the sensitivity or angle of variation for detection of out-of-balance may be poor—say, 1° or 2°. With constant practice in making daily observations, this sensitivity is reduced in the course of a month or so to something of the order of 0·5° or less under suitable conditions. The constant practice, moreover, results in a great reduction of the time of determination of the balance, and this factor makes for additional accuracy in the bearing obtained.

These results confirm the conclusions arrived at by Hollingworth in his experiments on the sensitivity of the ear to the reception of buzzer signals, as described in a paper to which reference has been previously made [2]. Owing to there being a range of optimum signal strength for the sensitivity of observations, an observer with a very keen ear does not possess a great advantage over one with a less sensitive ear, for, except with very weak signals, the latter observer may adjust the signal strength to the best value by means of the receiving amplifier.

Even in cases where the observer is fatigued by continued watching or from other causes, the actual bearing is not much

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affected, but the sensitivity of the observations may greatly decrease. It is not considered, however, that an observer can continue to take observations for more than two hours at a time without endangering the accuracy of the readings. Another effect of fatigue has been noticed in the case of listening to fairly loud signals; a period of several seconds must elapse before the ear has regained its sensitivity for very much weaker signals.

Although the usual sensitivity obtained in the determination of bearings is from 0·3° to 0·5°, successive readings at short intervals often agree to 0·1° to 0·2°, indicating that the mean reading of the bearing obtained is correct to within these limits.

This section thus provides experimental confirmation of the reliability of the individual installations to their rated value, viz., 1°, the actual instrumental error involved being often not greater than 0·5°. The later sections will show that an attempt to obtain a higher instrumental accuracy is not at present justified owing to the existence of much larger errors external to the apparatus.

(4) *Errors of Local Conditions on Direction Finders*

Various experiments have been carried out during the last two years on the effect of local conditions such as metal-work, overhead wires, trees, etc., on the readings of direction-finders. These experiments showed that some very large errors, ranging up to 22°, can be produced by the proximity of such obstacles, and emphasise the importance of exercising care in selecting a suitable site for a direction-finding installation.

As all these experiments have been described in detail in previous publications, it is considered unnecessary to do more than provide the references here[5].

Further remarks will be made on these effects in considering the actual results of the general investigation.

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SECTION II.—STATEMENT OF RESULTS OBTAINED TO MARCH, 1922

(5) *Statement of Results*

THE observations in the general investigation were originally made during three daily working periods, which were varied in a four-weekly cycle as follows :—

1st week	08.00 to 09.00	13.00 to 14.00	17.00 to 18.30
2nd week	09.00 to 10.00	14.00 to 15.00	18.00 to 19.30
3rd week	10.00 to 11.00	15.00 to 16.00	19.00 to 20.30
4th week	11.00 to 12.00	16.00 to 17.00	20.00 to 21.30

After the first three months terminating on May 30, 1921, these periods were altered as follows :—

	Morning Period.	*Evening Period.*
1st week ...	08.00 to 09.30	16.30 to 18.00
2nd week ...	09.00 to 10.30	18.00 to 19.30
3rd week ...	10.00 to 11.30	19.00 to 20.30
4th week ...	11.00 to 12.30	20.00 to 21.40

With the exception that the last evening period was later altered to terminate at 22.00, this programe of the periods of observation has been maintained up to the end of the period dealt with in this part of the main report.

During the period of the general investigation covered by the present report, the number of results collected for reduction, after a critical examination in which all inaccurate and doubtful readings were neglected, is over 41,000. In addition to these, several thousand observations have been made during special tests at various times throughout the investigation.

The distribution of these results among the places of observation is shown in the following table :—

Station.	Total number of observations collected to 4th March, 1922.
1. Aberdeen	3,233
2. Bangor	4,898
3. Belfast	1,091
4. Bristol	6,705
5. Cambridge	908
6. Leeds	1,670
7. Newcastle	9,918
8. Peterborough	3,319
9. Slough	1,339
10. Teddington	8,129
	41,210

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The abnormally low number of readings obtained at a few of the stations is accounted for by the fact that these were not in operation during the whole period, owing to change of observer or other conditions.

These results have been arranged first in weekly tables, showing the extreme and mean bearings obtained for each week, for the various periods of transmission where these are at all regular, and for morning and evening periods in the case of irregular transmissions.

While it is impracticable to reproduce here these weekly tables, the number of which exceeds 350, it is considered to be useful to give the following summaries for the whole period in Tables Nos. 5-14.

It may be remarked here that throughout the report all times are recorded in G.M.T., and all bearings are in angles (0°-360°) from geographical north. For the values of true bearings and distances of all transmitting stations these were, in general, calculated from the geographical position of the station. In the case of certain Eastern European stations information upon the geographical position was not available, and resort was had to the position of the town after which the station is named. In these instances, therefore, the "true" bearings may be as much as a degree in error. Even with the former stations, the geographical position recorded in different publications varies slightly, leading to some uncertainty in the calculated bearing. In general, however, these bearings are correct to a tenth of a degree, and in all possible cases they were checked from a gnomonic chart.

All the results recorded were taken on ordinary spark receivers without heterodyne, such C.W. signals as are mentioned being detected by the modulation or impurity of their wave-form.

The distribution of the observing stations and of the transmitting stations which have been utilised in this investigation is shown on the gnomonic chart (figure 41).

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TABLE 5.—SUMMARY OF OBSERVATIONS TAKEN AT ABERDEEN FROM 9.5.21 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	I.	4·6	299·2	133	2·3	+ 10·9	55	1·8	+ 10·4
Budapest	S. 3·0	I.	1,106	118·0	—	—	—	20	2·6	+ 14·7
Cleethorpes	S. 3·0	17.00	263	161·5	—	—	—	87	1·9	+ 1·4
Horsea	C.W. 6·0	12.00	458	174·3	8	1·2	+ 7·0	—	—	—
Karlsborg	S. 2·5	20.00	615	74·5	—	—	—	362	66·0	+ 8·4
Karlsborg	S. 4·2	I.	615	74·5	76	14·0	+ 3·2	—	—	—
Moscow	S. 5·0	I.	1,498	76·8	—	—	—	260	15·6	+ 6·4
Nantes	S. 4·2	08.15	689	178·5	5	1·6	— 6·0	—	—	—
Nauen	S. 3·9 3·2	11.50	670	111·4	116	2·2	+ 14·9	—	—	—

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Paris	S.	2·6	08.15	601	160·6	165	1·8	+ 1·3	—	—	—
Paris	S.	2·6	09.20	601	160·6	709	2·6	+ 1·3	—	—	—
Paris	S.	2·6	10.40 11.30	601	160·6	341	2·5	+ 1·3	—	—	—
Paris	S.	2·6	19.20	601	160·6	—	—	—	257	4·0	+ 1·3
Paris	S.	3·2	21.10 11.0	601	160·6	400	2·4	+ 1·4	—	—	—
Poldhu	S.	2·8	12.0 09.30 21.30	509	196·1	94	3·8	— 12·4	145	8·7	— 11·9

I = Irregular transmissions.

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TABLE 6.—SUMMARY OF OBSERVATIONS TAKEN AT BANGOR FROM 7.2.21 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	08.30 19.10	284	14·7	34	20·3	+ 1·3	18	2·2	+ 2·5
Aranjuez	S. 3·5	I.	912	176·5	—	—	—	7	9·5	+ 4·8
Budapest	S. 3·0	I.	1,085	101·9	32	3·5	— 7·1	114	17·9	— 5·6
Chelmsford	C.W. 3·8	I.	218	116·3	43	3·7	— 1·4	36	46·1	+ 2·9
Cleethorpes	S. 3·0 C.W. 3·0	17.00 & I. (day)	168	81·8	17	14·4	— 6·5	86	24·6	— 8·5
Clifden	C.W. 5·8	I.	244	275·9	180	6·3	— 0·7	141	64·7	+ 3·5
Coltano	S. 4·2	I.	935	129·3	77	2·9	— 3·1	13	11·6	— 2·6
Gibraltar	C.W. 4·8	I.	1,180	183·4	4	1·8	+ 12·9	5	34·5	+ 12·1
Horsea	C.W. 6·0 4·5	12.00 20.00	208	141·1	78	5·8	— 0·5	162	25·5	+ 0·5

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Karlsborg	S.	2·5	12.15	803	55·7	17	1·9	— 8·5	271	44·9	— 6·3
			20.00								
Karlsborg	S.	4·2	I.	803	55·7	79	7·9	— 4·7	63	22·1	— 4·3
Konigswusterhausen ..	C.W.	5·3	I.	743	87·8	92	6·6	— 7·5	—	—	—
Moscow	S.	4·8	I.	1,658	67·1	5	0·5	— 3·1	591	42·3	— 0·2
Nantes	S.	2·5	08.00	430	195·2	13	2·5	+ 5·9	22	3·6	+ 6·4
			21.00								
Nantes	S.	4·2	08.15	430	195·2	32	4·4	+ 2·4	19	9·0	+ 1·6
			21.30								
Nauen	S.	3·9	11.50	708	86·3	121	11·3	— 8·1	—	—	—
		3·2									
Nauen	C.W.	4·7	I.	708	86·3	21	5·8	— 11·6	55	23·5	— 13·1
Nicolaieff	S.	4·0	I.	1,639	90·6	5	2·2	— 7·0	52	12·9	— 5·0
Paris	S.	2·6	08.15	410	134·8	164	9·9	— 2·2	—	—	—
Paris	S.	2·6	09.20	410	134·8	506	5·7	— 2·1	—	—	—
			10.40								
Paris	S.	2·6	11.30	410	134·8	254	3·6	— 2·3	—	—	—
Paris	S.	2·6	19.20	410	134·8	—	—	—	211	26·5	— 1·6
			21.10								
Paris	S.	3·2	11.00	410	134·8	402	6·8	0·0	—	—	—
			12.00								
Poldhu	S.	2·8	09.30	228	193·0	172	3·5	+ 3·4	110	18·0	+ 4·7
			21.30								
Poldhu	S.	2·8	I.	228	193·0	18	1·8	+ 3·4	32	14·9	+ 4·3

I = Irregular transmissions.

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TABLE 7.—SUMMARY OF OBSERVATIONS TAKEN AT BELFAST FROM 1.8.21 TO 27.8.21, AND 17.12.21 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total variation.	Error of mean.	No.	Total variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Cleethorpes	C.W. 3·0	I.	250	104·7	10	3·0	+ 0·1	—	—	—
Coltano	S. 4·2	I.	1,052	129·2	31	1·5	+ 2·2	30	5·0	+ 3·0
Horsea	C.W. 4·5	12.00	328	140·1	9	2·0	+ 0·9	2	2·5	+ 0·7
Karlsborg	S. 2·5	20.00 20.00	818	62·6	—	—	—	43	22·8	+ 1·2
Karlsborg	S. 4·2	I.	818	62·6	36	5·0	+ 0·6	72	8·0	— 0·1
Moscow	S. 4·8	I.	1,692	69·1	—	—	—	185	18·0	+ 4·6
Nantes	S. 2·5	08.00 21.00	544	158·5	2	—	— 0·5	3	7·5	— 0·3
Nantes	S. 4·2	08.15 21.30	544	158·5	10	1·0	— 0·4	17	2·5	— 1·3
Nauen	S. 3·9 3·2	11.50	780	92·2	21	1·0	+ 1·6	—	—	—

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Nauen	C.W.	4·7	I.	780	92·2	77	5·5	+ 3·2	—	—	—
Paris	S.	2·6	08.15	529	135·1	105	6·0	+ 3·1	—	—	—
Paris	S.	2·6	09.20	529	135·1	154	6·5	+ 2·7	—	—	—
			10.40								
Paris	S.	2·6	11.30	529	135·1	67	6·0	+ 2·4	—	—	—
Paris	S.	2·6	19.20	529	135·1	—	—	—	48	8·5	+ 2·2
Paris	S.	3·2	11.00	529	135·1	90	2·5	— 2·5	—	—	—
			12.00								
Poldhu	S.	2·8	09.30	316	174·6	56	7·0	+ 4·7	23	6·0	+ 4·9
			21.30								

I = Irregular transmissions.

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TABLE 8.—SUMMARY OF OBSERVATIONS TAKEN AT BRISTOL FROM 7.2.21 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aranjuez	S. 3·5	I.	789	181·8	112	3·5	+ 3·9	242	11·6	+ 3·7
Budapest	S. 3·0	I.	1,005	97·3	49	5·0	− 3·2	316	27·4	+ 0·1
Chelmsford	C.W. 3·8	I.	133	80·2	244	4·6	− 2·1	169	17·0	− 2·6
Cleethorpes	S. 3·0	I.	178	35·9	21	3·6	+ 2·8	23	5·6	+ 3·3
Cleethorpes	S. 3·0	17.00	178	35·9	—	—	—	111	16·6	+ 0·7
Cleethorpes	C.W. 4·6	I.	178	35·9	13	11·5	+ 3·2	12	3·8	+ 4·4
Clifden..	S. 5·8	I.	341	296·7	38	3·2	− 1·8	68	13·0	+ 0·3
Coltano	S. 4·2	I.	809	126·8	42	1·7	− 3·1	40	5·5	− 2·7
Horsea	C.W. 3·0	I.	78	122·9	3	6·9	− 0·9	15	9·5	+ 0·9
Horsea	C.W. 4·0	I.	78	122·9	5	3·4	− 2·2	9	11·2	− 0·6
Horsea	C.W. 4·5	12.00	78	122·9	189	5·2	− 2·3	428	13·5	− 2·0
	6·0	20.00								
Horsea	C.W 5·0	I.	78	122·9	—	—	—	23	4·5	− 1·1

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Karlsborg	S.	2·5	20.00	828	47·6	—	—	—	340	47·7	+	1·2
Karlsborg	S.	4·2	I.	828	47·6	19	7·0	+ 1·0	25	6·2	+	1·4
Moscow	S.	4·8	I.	1,651	63·8	3	3·0	+ 1·0	1,245	24·0	+	1·0
Nantes	S.	2·5	08.00 21.00	298	172·0	1	—	+ 2·3	14	1·0	+	2·6
Nantes	S.	4·2	08.15 21.30	298	172·0	28	3·1	+ 1·5	14	5·0	+	1·9
Nauen	S.	3·9 3·2	11.50	662	76·8	155	4·2	— 1·8	—	—		—
Nauen	C.W.	4·7	I.	662	76·8	7	2·5	— 1·8	—	—		—
Nicolaieff	S.	4·0	I.	1,577	87·6	7	6·5	+ 0·5	8	3·5		0·0
Paris	S.	2·6	08.15	281	127·8	116	4·1	— 0·1	—	—		—
Paris	S.	2·6	09.20 10.40	281	127·8	566	5·7	— 0·3	—	—		—
Paris	S.	2·6	11.30	281	127·8	289	2·6	— 0·1	—	—		—
Paris	S.	2·6	19.30 21.10	281	127·8	—	—	—	247	17·4	+	0·4
Paris	S.	3·2	11.00 12.00	281	127·8	380	4·8	— 1·0	—	—		—
Paris	S.	2·6	I.	281	127·8	—	—	—	28	9·8	+	0·3
Poldhu	S.	2·8	09.30 21.30	152	230·6	145	1·8	0·0	156	26·0	—	1·8
Poldhu	S.	2·8	I.	152	230·6	79	8·1	+ 0·1	398	57·5	—	2·0
Sofia	S.	3·2	I.	1,348	106·4	—	—	—	24	8·1	—	2·0

I = Irregular transmissions.

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TABLE 9.—SUMMARY OF OBSERVATIONS TAKEN AT CAMBRIDGE FROM 11.4.21 TO 4.3.22 (INTERMITTENTLY)

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Chelmsford	C.W. 3·8	I.	35	153·3	—	—	—	19	2·0	+ 0·6
Cleethorpes	S. 3·0	17.00	92	356·1	—	—	—	33	4·0	+ 2·4
Horsea	C.W. 4·5	12.00 20.00	107	209·6	48	10·5	+ 0·9	36	14·5	+ 2·0
Karlsborg	S. 2·5	20.00	709	46·7	—	—	—	36	38·5	+ 10·3
Moscow	S. 4·8	I.	1,526	65·8	—	—	—	20	4·0	+ 0·3
Nauen	S. 3·9 3·2	11.50	535	81·7	52	7·5	+ 1·5	—	—	—
Paris	S. 2·6	08.15	250	156·4	68	4·0	+ 0·5.	—	—	—

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Paris ..	..	..	S.	2·6	09.20 10.40	250	156·4	250	5·0	+ 0·4	—	—	—
Paris ..	..	..	S.	2·6	11.30	250	156·4	50	5·0	+ 0·3	—	—	—
Paris ..	..	..	S.	2·6	19.30	250	156·4	—	—	—	96	5·5	+ 0·5
Paris ..	..	..	S.	3·2	11.00 12.00	250	156·4	99	6·0	+ 0·9	—	—	—
Poldhu	..	..	S.	2·8	09.30 21.30	275	239·0	55	7·5	+ 1·1	46	23·0	— 2·1

I = Irregular transmissions.

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TABLE 10.—SUMMARY OF OBSERVATIONS TAKEN AT LEEDS FROM 5.3.21 TO 23.7.21

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	I.	235	354·2	23	3·5	− 1·6	21	9·0	− 1·2
Aranjuez	S. 3·5	I.	953	185·3	43	2·5	+ 0·5	29	4·5	+ 0·5
Budapest	S. 3·0	I.	980	104·3	49	2·5	+ 0·1	127	8·3	+ 0·6
Chelmsford	C.W. 3·8	I.	166	148·5	40	3·0	− 3·5	34	8·0	− 3·2
Cleethorpes	S. 3·0	17.00	64	106·8	—	—	—	9	0·5	− 3·1
	C.W. 4·6	I.	64	106·8	14	1·0	− 1·9	19	2·5	− 3·1
Clifden	S. 5·8	I.	347	269·7	—	—	—	7	5·0	− 6·1
Horsea	C.W. 4·5	12.00 20.00	205	174·5	22	2·5	− 3·1	50	4·0	− 4·4
Karlsborg	S. 2·5	20.00	693	55·8	—	—	—	65	14·0	+ 2·6
Karlsborg	S. 4·2	I.	693	55·8	15	2·0	+ 0·9	—	—	—

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Moscow	S.	4·8	I.	1,546	69·1	7	2·5	+ 0·5	31	11·0	+ 2·3
Nantes	S.	2·5	21.00	457	180·8	—	—	—	3	6·0	− 2·8
Nauen	S.	3·9	11.50	602	91·2	63	1·0	0·0	—	—	—
Nicolaieff	S.	3·2 4·0	I.	1,536	94·5	15	1·5	− 0·8	6	4·0	− 1·0
Paris	S.	2·6	08.15	378	152·4	52	1·2	+ 0·8	—	—	—
Paris	S.	2·6	09.20	378	152·4	249	1·8	− 2·8	—	—	—
Paris	S.	2·6	10.40 11.30	378	152·4	126	1·0	− 2·7	—	—	—
Paris	S.	2·6	19.30	378	152·4	—	—	—	72	3·8	− 2·9
Paris	S.	3·2	21.10 11.00	378	152·4	140	1·7	− 3·4	—	—	—
Poldhu	S.	2·8	09.30	304	212·7	65	1·0	+ 3·0	2	0·2	+ 3·4
Poldhu	S.	2·8	21.30 I.	304	212·7	21	1·0	+ 2·8	37	4·5	+ 2·7
Sofia	S.	3·2	I.	1,363	114·0	—	—	—	19	3·0	− 2·4

I = Irregular transmission.

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TABLE 11.—SUMMARY OF OBSERVATIONS TAKEN AT NEWCASTLE FROM 28.2.21 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	I.	154	352·0	100	10·5	− 0·2	37	17·0	+ 0·1
Aranjuez	S. 3·5	I.	1,034	184·6	65	1·7	+ 2·0	102	5·6	+ 1·6
Budapest	S. 3·0	I.	1,026	111·6	45	3·5	− 1·3	527	29·5	− 1·1
Chelmsford	C.W. 3·8	I.	240	158·1	126	5·0	− 0·8	256	4·0	− 0·7
Cleethorpes	S. 3·0	17.00	118	147·2	—	—	—	87	4·2	− 0·9
Cleethorpes	C.W. 4·6	I.	118	147·2	72	9·3	− 0·8	134	12·0	− 1·5
Clifden	S. 5·8	I.	355	256·2	64	2·2	− 1·4	4	6·0	− 3·4
Clifden	C.W. 5·8	I.	355	256·2	95	7·5	− 0·3	182	33·0	− 0·1
Coltano	S. 4·2	I.	948	140·6	141	3·1	− 1·9	60	7·6	− 0·7
Horsea	C.W. 6·0	12.00	287	175·5	204	6·5	− 0·9	392	14·5	− 0·5
	4·5	20.00								
Karlsborg ..	S. 2·5	12.15	650	62·4	33	6·7	− 1·4	441	37·0	+ 1·7
		20.00								

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Karlsborg	S.	4·2	I.	650	62·4	207	10·2	− 1·2	128	23·0	+ 0·7
Karlsborg	C.W.	4·5	I.	650	62·4	27	2·3	− 0·6	9	4·0	− 2·3
Moscow	S.	4·8	I.	1,521	71·8	18	2·4	− 0·4	1,838	34·0	+ 0·8
Nantes	S.	2·5	08.00 21.00	538	180·4	2	0·3	0·0	8	7·6	+ 0·2
Nantes	S.	4·2	08.15 21.30	538	180·4	6	1·3	− 2·9	5	2·0	+ 0·4
Nauen	S.	3·9 3·2	11.50	612	99·2	269	3·4	− 2·5	—	—	—
Nauen	C.W.	4·7	I.	612	99·2	50	13·5	− 3·1	27	13·5	− 2·4
Nicolaieff	S.	4·0	I.	1,546	96·3	160	5·8	− 0·7	106	12·8	+ 1·0
Paris	S.	2·6	08.15	454	156·9	202	3·0	− 2·2	—	—	—
Paris	S.	2·6	09.20 10.40	454	156·9	1,138	4·3	− 2·2	—	—	—
Paris	S.	2·6	11.30	454	156·9	605	3·1	− 2·3	—	—	—
Paris	S.	2·6	19.20 21.10	454	156·9	—	—	—	448	8·5	− 2·1
Paris	S.	3·2	11.00 12.00	454	156·9	537	3·0	− 0·5	—	—	—
Poldhu	S.	2·8	09.30 21.30	374	205·6	365	5·2	+ 0·3	172	32·5	− 1·0
Poldhu	S.	2·8	I.	374	205·6	14	1·5	+ 0·3	17	26·2	− 4·5
Sofia	S.	3·2	I.	1,400	116·8	7	2·8	− 2·2	166	11·5	+ 0·4
Warsaw	S.	2·0	I.	942	92·0	60	4·0	+ 0·8	23	5·6	+ 0·2

I = Irregular transmission.

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TABLE 12.—SUMMARY OF OBSERVATIONS TAKEN AT PETERBOROUGH FROM 26.3.21 TO 12.11.21

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	I.	326	347·0	13	1·5	+ 0·6	—	—	—
Aranjuez	S. 3·5	I.	878	189·9	—	—	—	7	6·5	+ 3·4
Budapest	S. 3·0	I.	921	104·8	31	6·5	− 0·4	145	17·0	+ 1·2
Chelmsford	C.W. 3·8	I.	67·5	153·1	31	4·0	+ 3·1	36	3·5	+ 3·0
Cleethorpes	S. 3·0	17.00	68	6·6	—	—	—	62	2·5	+ 0·9
Clifden	S. 5·8	I.	410	282·1	46	8·0	+ 0·3	9	0·5	− 0·8
Horsea	C.W. 4·5	12.00 20.00	127	197·3	104	4·0	+ 0·3	177	20·0	+ 0·5
Karlsborg	S. 2·5	20.00	700	48·8	—	—	—	229	30·0	+ 1·9
Karlsborg	S. 4·2	I.	700	48·8	31	3·0	− 0·9	—	—	—

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Moscow	S.	4·8	I.	1,527	66·7	5	0·5	− 0·6	574	19·0	+ 1·1
Nicolaieff	S.	4·0	I.	1,476	92·3	11	2·0	+ 0·2	9	7·5	+ 1·8
Nauen	S.	3·9 3·2	11.50	550	84·3	92	2·5	+ 0·1	—	—	—
Paris	S.	2·6	08.15	281	155·8	112	0·6	+ 1·4	—	—	—
Paris	S.	2·6	09.20 10.40	281	155·8	410	1·2	+ 1·4	—	—	—
Paris	S.	2·6	11.30	281	155·8	225	1·2	+ 1·5	—	—	—
Paris	S.	2·6	19.30 21.10	281	155·8	—	—	—	166	7·7	+ 1·0
Paris	S.	3·2	11.00 12.00	281	155·8	250	1·2	+ 1·8	—	—	—
Poldhu	S.	2·8	09.30 21.30	280	232·7	224	4·0	+ 0·2	108	22·0	− 1·5
Poldhu	S.	2·8	I.	280	232·7	—	—	—	52	6·0	+ 0·5
Sofia	S.	3·2	I.	1,280	112·8	—	—	—	42	24·0	+ 3·8
Warsaw	S.	2·0	I.	892	83·0	—	—	—	8	22·3	+ 7·1

I = Irregular transmissions.

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TABLE 13.—SUMMARY OF OBSERVATIONS TAKEN AT SLOUGH FROM 9.1.22 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total varia-tion.	Error of mean.	No.	Total varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Chelmsford	C.W. 3·8	I.	47	69·9	110	11·9	− 0·8	99	14·6	− 1·7
Coltano	S. 4·2	I.	742	132·5	139	4·0	+ 0·5	34	8·5	+ 1·3
Horsea	C.W. 4·5	12.00 20.00	50	207·7	24	1·8	+ 0·3	14	5·5	− 0·1
Karlsborg	S. 2·5	20.00	764	44·9	—	—	—	42	20·5	+ 2·8
Karlsborg	S. 4·2	I.	764	44·9	55	5·4	− 1·9	97	23·0	− 3·6
Moscow	S. 4·8	I.	1,572	64·2	—	—	—	201	18·0	+ 0·4
Nantes	S. 2·5	08.00 21.00	302	190·2	—	—	—	2	3·1	+ 1·4
Nantes	S. 4·2	08.15 21.30	302	190·2	—	—	—	3	0·8	+ 2·3
Nauen	S. 3·2	11.50	576	76·7	33	2·1	− 0·4	—	—	—

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Nauen	C.W.	4·9	I.	576	76·7	7	2·2	− 1·8	18	11·5	+ 3·0
Nicolaieff	S.	4·0	I.	1,489	89·5	58	3·5	− 1·3	4	4·0	− 0·3
Paris	S.	2·6	08.15	221	143·9	32	1·8	+ 0·7	—	—	—
Paris	S.	2·6	09.20	221	143·9	148	3·1	+ 0·7	—	—	—
Paris	S.	2·6	10.40 11.30	221	143·9	35	1·0	+ 1·0	—	—	—
Paris	S.	2·6	19.30	221	143·9	—	—	—	65	5·4	+ 1·0
Paris	S.	3·2	21.10 11.00	221	143·9	31	0·9	+ 1·1	—	—	—
Poldhu	S.	2·8	12.00 09.50	228	245·7	38	3·5	0·0	13	9·2	− 5·1
Sofia	S.	3·2	21.50 I.	1,265	109·2	3	0·5	+ 0·5	16	4·0	+ 0·4

I = Irregular transmission.

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TABLE 14.—SUMMARY OF OBSERVATIONS TAKEN AT TEDDINGTON FROM 7.2.21 TO 4.3.22

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Total variation.	Error of mean.	No.	Total variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aranjuez	S. 3·5	I.	797	190·5	—	—	—	20	5·5	+ 1·5
Budapest	S. 3·0	I.	908	99·7	144	6·2	− 0·3	307	19·3	+ 0·8
Chelmsford	C.W. 3·8	I.	41	58·9	667	7·3	− 1·1	682	19·3	− 1·3
Cleethorpes	S. 3·0	17.00	146	4·5	—	—	—	84	10·1	0·0
Clifden	S. 5·8	I.	430	292·8	47	3·6	+ 1·2	—	—	—
Coltano	S. 4·2	I.	731	133·0	194	3·4	− 1·3	51	20·7	+ 0·5
Horsea	C.W. 6·0	12.00	52	220·2	125	2·9	− 1·1	328	8·3	− 1·0
	4·5	20.00								
Karlsborg	S. 2·5	12.15	760	44·4	6	3·0	+ 0·7	320	34·5	+ 2·8
		20.00								
Karlsborg	S. 4·2	I.	760	44·4	60	6·9	+ 0·3	112	23·6	− 1·6
Moscow	S. 4·8	I.	1,565	64·0	37	4·7	+ 1·7	1,255	44·5	+ 2·7

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Nantes	S.	2·5	08.00 21.00	296	192·3	10	1·3	− 0·6	39	7·8	+ 0·3
Nantes	S.	4·2	08.15 21.30	296	192·3	38	4·3	− 1·4	46	14·9	+ 0·8
Nauen	S.	3·9 3·2	11.50	575	76·3	186	3·5	+ 1·9	—	—	—
Nicolaieff	S.	4·0	I.	1,479	89·2	62	4·4	+ 0·4	45	12·0	+ 1·7
Paris (FL)	S.	2·6	08.15	211	145·6	312	7·7	− 0·2	—	—	—
Paris	S.	2·6	09.20	211	145·6	599	3·7	− 0·1	—	—	—
Paris	S.	2·6	10.40 11.30	211	145·6	272	4·7	0·0	—	—	—
Paris	S.	2·6	19.30	211	145·6	—	—	—	242	6·3	− 0·2
Paris	S.	3·2	21.10 11.00	211	145·6	357	2·8	− 0·3	—	—	—
Paris (UFP)	C.W.	2·4	12.00 I.	211	145·6	305	7·5	− 0·3	203	22·3	0·0
Poldhu	S	2·8	09·30	235	247·9	295	3·7	+ 1·5	190	38·3	− 1·5
Poldhu	S.	2·8	21·30 I.	235	247·9	—	—	—	30	19·0	− 0·8
Sofia	S.	3·2	I.	1,254	109·3	—	—	—	178	18·0	+ 2·2
Warsaw	S.	2·0	I.	910	78·0	21	6·1	+ 1·3	14	2·4	+ 2·6
Whitehall	C.W.	3·3	09.00	10	58·0	48	3·0	+ 0·1	23	3·3	+ 0·3
Whitehall	C.W.	3·3	17.00 21.00	10	58·0	—	—	—	23	3·4	− 0·1

I = Irregular transmission.

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(6) *Specimen weekly summary sheets*

As a specimen of the weekly summary sheets from which the above tables are obtained, the sheets for the observation of bearings of Poldhu at the morning and evening transmissions, at both Teddington and Newcastle, are given below (Tables 15–18). On these sheets the standard deviation of the individual observations from their weekly and annual mean is also given: Although this figure clearly indicates that the extent of variation of the observed bearings may give an entirely false impression of the magnitude of the normal error, it was not considered to be of sufficient value to justify the great labour involved in the calculation of this quantity for every set of observations. It is interesting to note, however, that the standard deviations of Poldhu's bearing at Newcastle and Teddington are 3·5° and 4·3° respectively at night, while the total variations observed are 32·5° and 38·3°. By day the corresponding deviations are 0·5° and total variations are 5·2° and 3·7° respectively.

In column 3 of these tables the " accuracy " of the individual observations is given, using the notation I, II and III. An accuracy I indicates that at the time of taking the bearing the displacement of the coil system necessary to disturb definitely the balance of signal strength is less than 1° on either side of the mean position, which is the bearing recorded. In the large majority of cases observations recorded to an accuracy I were well defined to 0·5°, and with some signals under favourable conditions an accuracy of 0·2° is obtained. It should be emphasised that, at accuracy I, the total angle of swing of the coil system, while still retaining a balance of signal strength, is less than 2°, but the reading recorded, which is midway in the angle of balance, is probably an accurate observation of the apparent bearing to the order of 0·2° or 0·1°. Corresponding remarks apply to the notations II and III referring to displacements of 1° to 2°, and 2° to 3° respectively. No numerical observations were taken when the " accuracy " was observed to be greater than 3°, a suitable note being made as to the cause of such low accuracy which might be due to either weak signals, interference from signals or atmospherics, or the existence of an excessively flat minimum. This fact is very important in analysing the tabulated data accompanying this section, since with an extreme displacement of the system of 3° or less for the determination of the balance position, an observational error of a greater order than 1° is practically impossible, neglecting the few cases in which a misreading of the scale by 5° or 10° is made.

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TABLE 15.—OBSERVING STATION—NEWCASTLE
Transmitting Station—Poldhu ; *Time*, 09.30 and 09.50 ;
$\lambda = 2 \cdot 8$ km. Spark.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Week ending.	No. of observations.	Accuracy.	Extreme bearings.	Mean bearing.	Total variation.	Maximum deviation from mean.	Standard deviation from mean.
			(deg.)	(deg.)	(deg.)	(deg.)	(deg.)
12.3.21	6	I–II (1 reading at II)	206·3 205·7	206·0	0·6	± 0·3	0·2
16.4.21	9	I–II (4 at II)	205·5 204·0	205·1	1·5	− 1·1	0·5
7.5.21	4	I ..	206·3 206·0	206·1	0·3	+ 0·2	0·1
14.5.21	17	I ..	206·0 205·7	205·8	0·3	+ 0·2	0·1
4.6.21	14	I ..	206·0 205·7	205·9	0·3	− 0·2	0·1
11.6.21	15	I (2 at II)	206·5 205·0	206·0	1·5	− 1·0	0·4
2.7.21	17	I ..	206·5 205·6	206·0	0·9	+ 0·5	0·3
9.7.21	16	I ..	206·0 205·5	205·8	0·5	− 0·3	0·2
30.7.21	22	I ..	205·9 205·3	205·6	0·6	± 0·3	0·1
6.8.21	11	I ..	206·0 205·0	205·6	1·0	− 0·4	0·3
27.8.21	21	I ..	206·0 205·5	205·7	0·5	+ 0·3	0·2
3.9.21	28	I ..	206·0 205·4	205·8	0·6	− 0·4	0·2
24.9.21	21	I ..	205·8 205·3	205·5	0·5	+ 0·3	0·1
1.10.21	25	I ..	205·9 205·4	205·6	0·5	+ 0·2	0·1
22.10.21	25	I ..	206·2 205·6	205·9	0·6	± 0·3	0·2
29.10.21	21	I ..	206·5 204·8	205·9	1·7	− 0·9	0·5
19.11.21	19	I ..	208·7 205·1	206·2	3·6	+ 2·5	1·2
26.11.21	14	I ..	208·0 205·4	206·7	3·4	± 1·3	0·9
17.12.21	16	I ..	206·8 204·4	205·7	2·4	+ 1·1	0·7
24.12.21	11	I ..	207·1 203·5	205·5	3·6	− 2·0	1·5
14.1.22	8	I ..	206·6 205·1	206·0	1·5	− 0·9	0·6
21.1.22	15	I ..	206·6 205·7	206·0	0·9	+ 0·6	0·3
18.2.22	10	I ..	207·1 205·8	206·5	1·3	− 0·7	0·5
Whole Period	365	358 at I 7 at II	208·7 203·5	205·9	5·2	+ 2·8	0·5

True bearing = 205·6°. Error of mean = +0·3°. Total Variation = 5·2°.

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TABLE 16.—OBSERVING STATION—NEWCASTLE

Transmitting Station—Poldhu; *Time*, 21.30 and 21.50; $\lambda = 2 \cdot 8$ km. Spark.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Week ending.	No. of observations.	Accuracy.	Extreme bearings.	Mean bearing.	Total variation.	Maximum deviation from mean.	Standard deviation from mean.
			(deg.)	(deg.)	(deg.)	(deg.)	(deg.)
30.4.21	9	I–II (2 at II)	203·0 201·0	202·3	2·0	− 1·3	0·7
28.5.21	15	I ..	206·0 204·8	205·5	2·8	− 0·7	0·4
25.6.21	15	I ..	206·8 205·5	206·1	1·3	+ 0·7	0·4
23.7.21	16	I (3 at II)	210·0 202·0	205·0	8·0	+ 5·0	1·9
20.8.21	3	I (1 at II)	211·5 211·0	211·3	0·5	− 0·3	0·2
17.9.21	20	I–III (10 at II, 2 at III)	216·5 195·0	203·6	21·5	+12·9	5·5
15.10.21	10	I–III (2 at II, 2 at III)	205·7 200·0	204·4	5·7	− 4·4	2·0
12.11.21	19	I–II (6 at II)	216·0 206·0	212·2	10·0	− 6·2	2·6
10.12.21	15	I–III (5 at II, I at III)	204·5 184·0	196·7	20·5	−12·7	5·6
7.1.22	12	1 at I, 9 at II, 2 at III	207·2 199·0	203·5	8·2	− 4·5	2·6
4.2.22	23	10 at I, 12 at II, 1 at III	208·5 193·0	202·5	15·5	− 9·5	4·6
4.3.22	15	4 at I, 8 at II, 3 at III	213·0 201·0	204·9	12·0	+ 8·1	3·5
Whole Period	172	103 at I, 58 at II, 11 at III	216·5 184·0	204·6	32·5	−20·6	3·5

True bearing = 205·6°. Error of mean = −1·0°. Total variation = 32·5°.
Difference of means; Night to day = −1·3°.

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TABLE 17.—OBSERVING STATION—TEDDINGTON

Transmitting Station—Poldhu; *Time*, 09.30 and 09.50; $\lambda = 2 \cdot 8$ km. Spark.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Week ending.	No. of observations.	Accuracy.	Extreme bearings.	Mean bearing.	Total variation.	Maximum deviation from mean.	Standard deviation from mean.
			(deg.)	(deg.)	(deg.)	(deg.)	deg.)
12.2.21	18	I	251·0 / 249·1	250·0	2·1	+ 1·0	0·6
12.3.21	6	I	250·9 / 249·0	250·3	1·9	− 1·3	0·9
16.4.21	17	I	250·8 / 249·6	249·9	1·2	+ 0·9	0·3
7.5.21	7	I	250·5 / 249·2	249·7	1·3	+ 0·8	0·5
14.5.21	6	I	250·0 / 249·0	249·6	1·0	− 0·6	0·3
28.5.21	4	I	250·0 / 249·1	249·7	0·9	− 0·6	0·3
4.6.21	13	I	250·4 / 249·0	249·6	1·4	+ 0·8	0·4
11.6.21	15	I	251·5 / 249·4	249·8	2·1	+ 1·7	0·5
2.7.21	21	I	249·7 / 248·8	249·2	0·9	+ 0·5	0·3
30.7.21	25	I	250·2 / 248·5	249·3	1·7	− 0·8	0·4
6.8.21	13	I	249·8 / 248·6	249·3	1·2	− 0·7	0·4
22.10.21	23	I	249·9 / 248·8	249·3	1·1	+ 0·6	0·3
29.10.21	19	I	250·1 / 248·6	249·5	1·5	− 0·9	0·4
19.11.21	24	I	250·2 / 247·8	249·0	2·4	± 1·2	0·7
26.11.21	7	I	250·6 / 248·3	249·2	2·3	+ 1·4	0·7
17.12.21	18	I	249·8 / 246·9	249·0	2·9	− 2·1	0·7
24.12.21	13	I	251·0 / 248·7	249·6	2·3	+ 1·4	0·4
14.1.22	18	I	250·0 / 249·0	249·5	1·0	± 0·5	0·3
21.1.22	15	I	250·7 / 249·0	249·6	1·7	+ 1·1	0·3
18.2.22	13	I	249·0 / 250·3	249·6	1·3	+ 0·7	0·4
Whole Period	295	I	251·5 / 247·8	249·4	3·7	+ 2·0	0·5

True bearing = 247·9°. Error of mean = + 1·5°. Total variation = 3·7°.

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TABLE 18.—OBSERVING STATION—TEDDINGTON

Transmitting Station—Poldhu; *Time*, 21.30 and 21.50; $\lambda = 2{\cdot}8$ km. Spark.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Week ending.	No. of observations.	Accuracy.	Extreme bearings.	Mean bearing.	Total variation.	Maximum deviation from mean.	Standard deviation from mean.
			(deg.)	(deg.)	(deg.)	(deg.)	(deg.)
26.2.21	11	I	247·9 233·0	242·2	14·9	− 9·2	4·4
26.3.21	5	I (1 at II)	251·2 237·5	245·0	13·7	− 7·5	6·0
30.4.21	11	I–II (3 at II)	252·4 239·9	246·0	12·5	+ 6·4	3·5
28.5.21	14	I	250·5 247·5	249·2	3·0	− 1·7	0·9
25.6.21	19	I (1 at II)	249·7 247·5	248·9	2·2	− 1·4	0·7
23.7.21	22	I	248·7 243·3	246·3	5·4	− 3·0	1·3
20.8.21	16	I	248·0 236·7	243·2	11·3	− 6·5	3·2
12.11.21	11	I	265·0 249·5	257·6	15·5	− 8·1	5·7
10.12.21	15	I	250·0 247·7	249·1	2·3	− 1·4	0·7
7.1.22	23	I	250·5 226·7	242·0	23·8	−15·3	6·2
4.2.22	21	I (1 at II)	258·7 244·6	250·4	14·1	+ 8·3	4·7
4.3.22	22	I	252·3 231·6	245·7	20·7	−14·1	6·7
Whole Period	190	184 at I, 6 at II	265·0 226·7	246·4	38·3	−19·7	4·3

True bearing = 247·9°. Error of mean = −1·5°. Total variation = 38·3°
Difference of means: Night to Day = − 3·1°.

SECTION III — DISCUSSION OF RESULTS — DAY OBSERVATIONS

(7) *Permanent Deviations*

THE first noticeable point in the results summarised in the foregoing tables is that the mean observed bearing of a transmitting station from a receiving station usually differs from the true bearing by an amount which ranges up to as much as 15°. The second point to be noted is that the range of variation of the observed bearings is in general very much greater in the evening periods than in the morning periods of observation. From this latter

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consideration it would appear that the mean of the morning observations is subject to less error than the mean of the evening observations, and the former will accordingly be used in the first consideration of the " permanent deviations," *i.e.*, the difference between the mean day bearings and the true bearings of the various transmitting stations. Previous general experience has shown that these permanent deviations are usually local to the receiving station, and it will, therefore, be most convenient to discuss them for each receiving station individually. It has already been shown in Section I (3) above that at Teddington the possible instrumental error is of the order of 0·5° and certainly not greater than 1°, this installation being taken as typical of the remainder.

(*a*) *Aberdeen* (*Table* 5).—This station is observed to possess the largest permanent deviations of any of the group ; the difference between day mean and true bearing varying from — 12·4° to + 14·9°. A graph showing the relation between the permanent

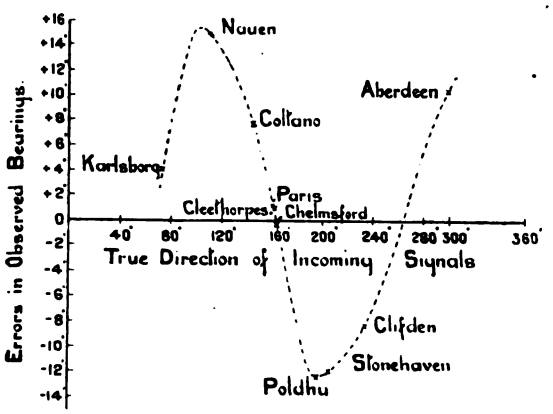

FIG. 1.—SHOWING PERMANENT DEVIATIONS IN BEARINGS AT ABERDEEN UNIVERSITY D.F. STATION.

(Mean Day Errors observed : June, 1921, to April, 1922.)

deviation and the true direction of the incoming waves is given in Fig. 1. The fact that the points so plotted result in a smooth curve indicates that the deviation is due to local conditions at the receiver. The majority, if not all, of this deviation has already been shown to be due to a long iron plate beneath the ground and supporting a sewer duct, over which the direction-finding installation was inadvertently erected. This matter has been fully reported on in a previous publication (*see* Ref. 5).

(*b*) *Bangor* (*Table* 6).—Large permanent deviations, ranging from — 11·9° to + 12·9°, are also experienced at this station. A graph of the deviations on the same basis as formerly gives a very irregular curve, which probably indicates that the whole of the deviation is not due to one cause. An effect that obviously contributes to the irregularity is the comparatively large change

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in the error with change in wave-length, as will be seen from Table 6.

It will be noticed that, with the exception of Nauen, the observed error decreases with increase of wave-length. With Nauen there is a change from damped to undamped waves accompanying the change in wave-length, so that the comparison is not quite a rigid one. In connection with these permanent deviations it is to be noted that the variations observed in the daytime at Bangor are in general larger than those observed at other stations.

While the exact cause of these errors at Bangor is not quite clear from the results, the local conditions at the site of this station probably account for them. The hut containing the direction-finding set was erected on slightly sloping ground a

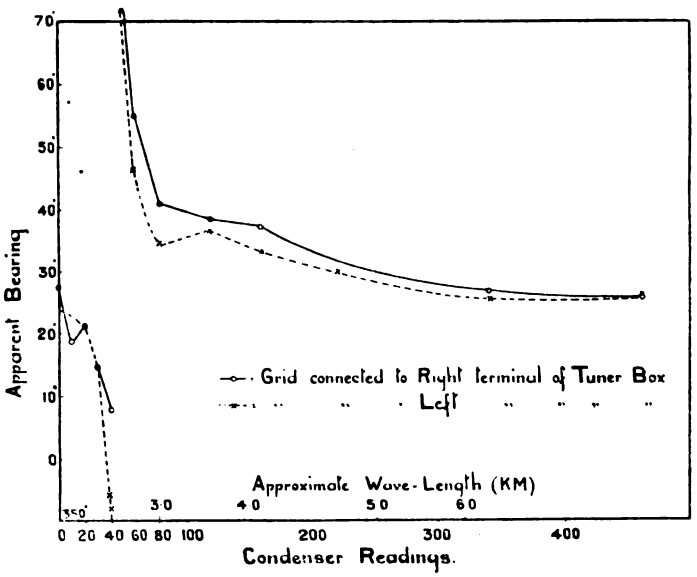

FIG. 2.—CURVES SHOWING CHANGE IN APPARENT BEARING OF CARNARVON ($\lambda = 14$ KM.) AT BANGOR UNIVERSITY, WITH CHANGE IN VALUE OF TUNING OF D.F. RECEIVER.

short distance from a small cliff above the seashore. A line of telegraph wires passed along below this cliff at a distance of about 80′ from the hut, and there were several small trees within a short distance. Also the surrounding district is very mountainous, particularly to the South and South-West. Another feature of the Bangor station which should not be neglected is that it was only 9·7 miles from the Carnarvon radio transmitting station. As this station uses a wave-length of 14·4 km., the direction-finder was little more than one wave-length from this high-power transmitter. Some curious effects resulting from the reception of signals from Carnarvon when the latter was using the timed-spark system have already been noted (*see* p. 9 and Fig. 2).

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In view of these complex circumstances it has not been considered useful to investigate the permanent errors of the Bangor station in any further detail.

(*c*) *Belfast* (*Table* 7).—The permanent day errors at this station range up to 4·7° and are fully accounted for by the fact that the set was erected on the roof of a building immediately over large iron girders.

(*d*) *Bristol* (*Table* 8).—At this station the permanent deviations range up to nearly 4°, and it is to be observed that in several cases there is a change in the error with change in wave-length. The installation at Bristol was erected on the top of a stone tower about 60′ above the ground, and practically on a level with several large trees surrounding the tower. Experiments carried out on this site have shown that these trees may easily account for the errors observed, and that moving a direction-finding set about amongst the trees may produce changes in the error amounting to nearly 9° (*see* Ref. 5).

(*e*) *Cambridge* (*Table* 9).—The site at this station was considered to be very good, it being on flat country free from trees, buildings, overhead wires and other obstructions for a distance of at least 600′ in every direction. The number and variety of the results obtained from this station are, unfortunately, very few, but those tabulated show that the permanent day deviations observed are, in a few cases, slightly in excess of the possible instrumental error. In the circumstances, these deviations can only be put down to the cause of the variable errors experienced, which, it will be noted, are much greater than the error of the mean, and which will receive further consideration.

(*f*) *Leeds* (*Table* 10).—Here, again, the site was admittedly not a good one, the set being erected at the top of a brick tower with iron supporting structure and an iron spiral staircase. These conditions would easily account for the 3° or 4° of permanent errors experienced. It is to be noted that, at this station, the variations in the day observations are somewhat unusually small.

(*g*) *Newcastle* (*Table* 11).—Several of the permanent deviations observed at this station are in excess of the instrumental error, and most of them are seen to be subject to change with change in wave-length. As the local conditions surrounding the set at Newcastle were very good, and it would be difficult to ascribe such errors to them, the cause must be sought elsewhere. As in the case of Cambridge, it is to be concluded that the origin of these errors is the same as that of the variations, which are of much greater magnitude, even in the daytime.

(*h*) *Peterborough* (*Table* 12).—At Peterborough the site was again very good except for the existence of some receiving aerials and loops in the vicinity. These, however, were always tuned to much higher wave-lengths than those in the present observations, and it is interesting to note that in this condition the aerials did

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not add materially to the errors of the direction-finder—a fact which confirms previous experiments on this point (*see* Ref. 5).

(*i*) *Slough* (*Table* 13).—The site at the Slough station was considered to be very good, being on very flat ground in an open field. With the exception of some power lines about a quarter of a mile away, there were no buildings or metal work of any description within a radius of over half a mile. The actual direction-finder was 300 to 400 feet from the nearest clumps of trees, which, however, were fairly extensive in the neighbourhood. In view of these facts it is significant that in one or two cases the permanent error of observed bearings is appreciable, although less than 2°.

(*j*) *Teddington* (*Table* 14).—Considering the local conditions surrounding the direction-finder at Teddington, the errors of the mean day bearings are remarkably small. The set was here situated within 30 feet of large masses of trees, which extended for over a mile in some directions, and these trees should undoubtedly have had some effect upon arriving waves. The choice of the position of the set to keep the errors small had, in fact, been shown to be fairly critical, a change in position by one or two hundred feet producing a change in bearing of over 9° (*see* Ref. 5).

(8) *Change in bearing with change in wave-length*

In the foregoing discussion it might appear that the writer has too easily assumed that some errors are not applicable to the instrument. This attitude, however, receives support from the behaviour of the error observed on transmitting stations using more than one wave-length. Since the receivers were identical and were erected in the same manner, it is reasonable to assume that the instrumental errors were of the same order. The preceding tables show, however, that the difference in the error on two wave-lengths varied for different receiving stations over several degrees. It is also to be noted that where large differences were obtained, they frequently occurred for several transmitting stations at the same place.

(9) *Variable errors.* (*Magnitude of errors observed*)

In addition to the systematic errors of the mean observed bearings taken, the tabulated summaries above show that quite appreciable variations in the observed readings take place in the day periods. While these variations are always quite small compared with those obtained in the evening periods, the results obtained to date are so numerous and so confirmatory for the different receiving stations that they prove beyond doubt the existence of variations in observed bearings in the daytime. While the readings on the whole show an extreme departure from the mean of 3° to 4°, corresponding to a total variation of about 7°, there are several cases of much larger variations, details of which are extracted in the following Table, No. 19 :—

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TABLE NO. 19.—SHOWING DETAILS OF THE "DAY" VARIATIONS EXCEEDING 7°

1	2	3	4
Transmitting Station.	Receiving Station.	Range of variation.	Remarks.
		(degrees)	
Aberdeen, C.W.	Bangor ..	20·3	Largest variations about 1 hr. after sunrise on 19.11.21.
,, ,,	Newcastle ..	10·5	Errors distributed.
Cleethorpes, ,,	Bangor ..	14·4	Largest variations within 1 hr. after sunrise. Same week at both receiving stations.
,, ,,	Bristol ..	11·5	
,, ,,	Newcastle ..	9·3	Experienced just after sunrise.
Clifden ,,	,, ..	7·5	Errors distributed.
,, ,,	Peterborough	8·0	,, ,,
Chelmsford ,,	Teddington ..	7·3	Errors distributed, but greatest about 1 hr. after sunrise.
,, ,,	Slough ..	11·9	Greatest about 1½ hrs. after sunrise.
Horsea ,,	Cambridge ..	10·5	Noon observations.
Karlsborg, S. ..	Aberdeen ..	14·0	Errors distributed, but readings of low accuracy.
,, ,,	Bangor ..	7·9	Faint signals several hours after sunrise.
,, ,,	Newcastle ..	10·2	Greatest errors about 2 hrs. after sunrise.
Nauen ,,	Bangor ..	11·3	Noon observations. Sudden change in bearing of over 4° on 15.10.21, not due to change in wave-length.
,, ,,	Cambridge ..	7·5	Noon observations.
,, C.W.	Newcastle ..	13·5	Greatest errors within 1 hr. after sunrise.
Paris, S.	Bangor ..	9·9	Largest variations obtained at ½ and 1 hr. after sunrise.
,, ,,	Teddington ..	7·7	Largest variations obtained within 1 to 1½ hrs. after sunrise.
Poldhu ,,	Cambridge ..	7·5	Observations 5 hrs. after sunrise.

From this table it is seen that the majority of these abnormally large day variations have occurred within about an hour after sunrise, and they may, therefore, reasonably be attributed to a residual "night effect." There are, however, one or two instances of variations, even as great as 14°, occurring several hours after sunrise. As the majority of all the observations have an accuracy

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of less than 1°, and in no case of greater than 3°, it appears to be impossible to attribute these variations to instrumental or observational errors, although it is to be admitted that, in a few isolated cases, a misreading of the scale by 10° is possible. While the effect of interference in giving a false bearing on weak received signals is not to be neglected, the ordinary "spark" signals received from such stations as Paris, Nauen and Poldhu are so strong, at any rate in the South of England, as to render interference errors quite negligible.

(10) *Weekly variation curves*

In Figures 3 to 8 are shown plotted the extreme bearings observed at various receiving stations over periods of one week of

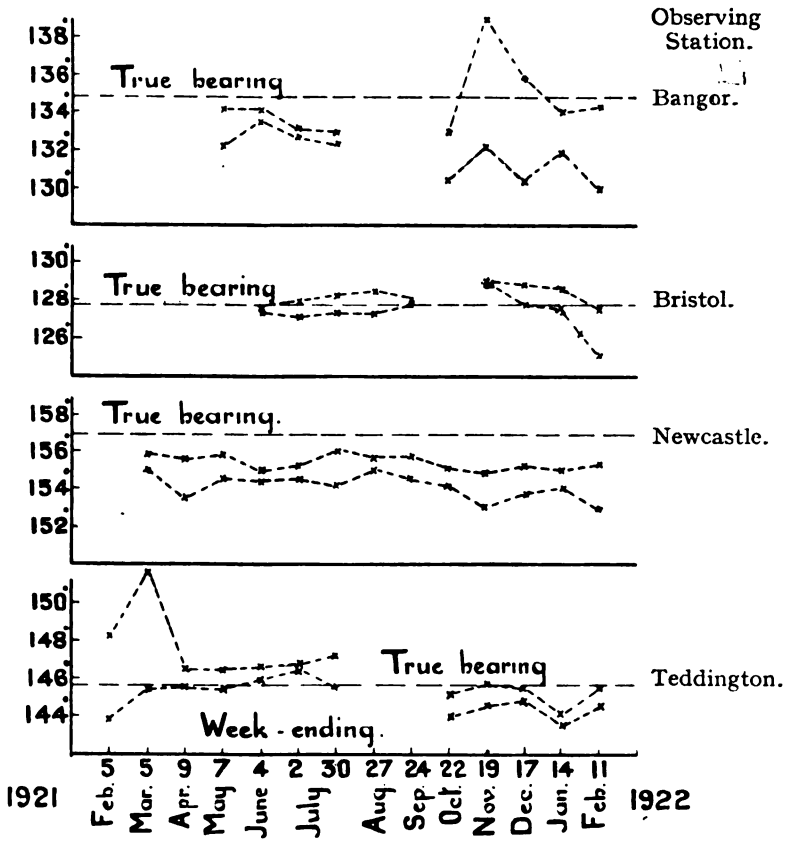

FIG. 3.—GRAPHS OF WEEKLY EXTREME BEARINGS OF PARIS (DAMPED WAVES, $\lambda = 2{\cdot}6$ KM.), AT THE 08.15 TRANSMISSIONS.

the different transmitting stations having a definite time of transmission daily. Full details as to date and time, etc., are given on the individual diagrams, and the majority of the observations plotted were recorded to an accuracy of I (*i.e.*, 1°), although

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in a few cases of weak signals, such as Horsea at Newcastle (without heterodyne), and Poldhu at Aberdeen, the accuracy was

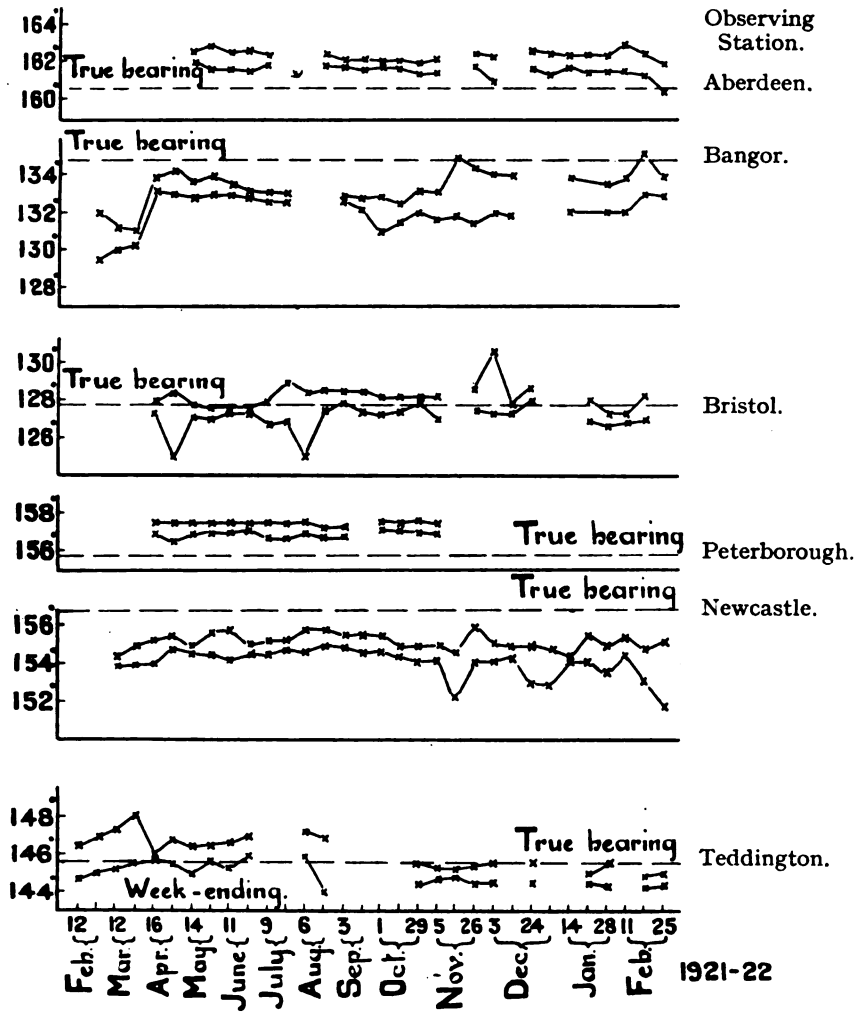

FIG. 4.—GRAPHS OF WEEKLY EXTREME BEARINGS OF PARIS (DAMPED WAVES, $\lambda = 2{\cdot}6$ KM.) AT THE 09.20 AND 11.00 TRANSMISSIONS.

reduced to II and III. Referring to these diagrams, the following points may be noted :—

(*a*) In general the extreme values of a week's readings differ by from 1° to 2°.

(*b*) At intervals, more frequent at Bangor than elsewhere, the extreme bearings over a week may differ by larger amounts up to 7°.

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(*c*) The extreme values from one week to another occasionally differ by a much greater amount than the general weekly variation. Here, again, Bangor provides the most marked instances of this effect.

(*d*) There appears to be no seasonal variation on any transmitting station where the observations are made well after sunrise. The spreading of the observed bearings

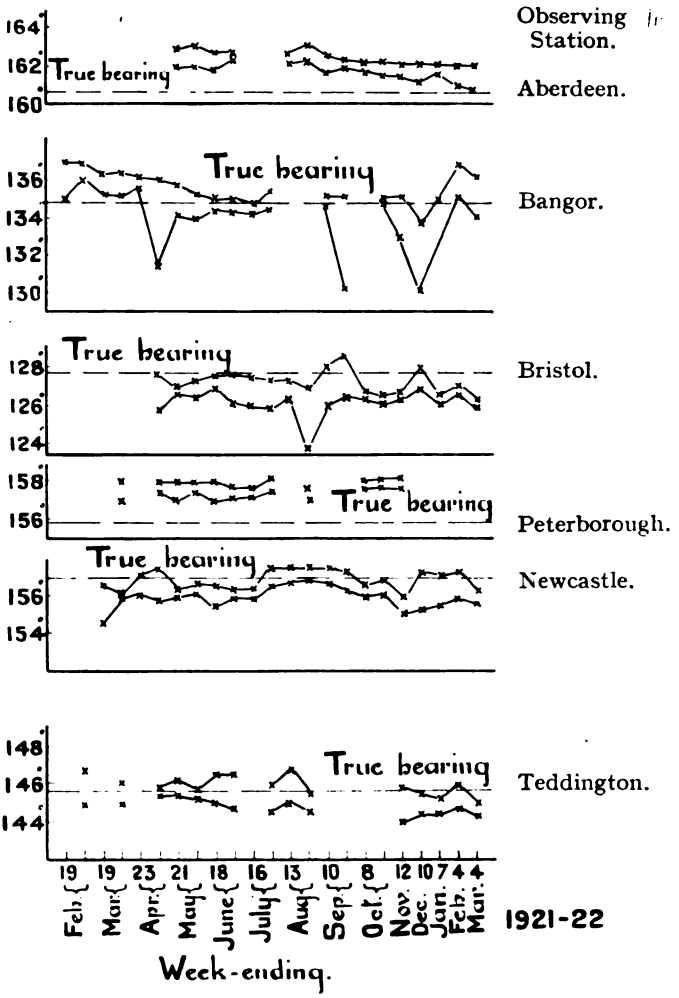

FIG. 5.—GRAPHS OF WEEKLY EXTREME BEARINGS OF PARIS (DAMPED WAVES, $\lambda = 3{\cdot}2$ KM.) AT THE 11.00 AND 12.00 TRANSMISSIONS.

of Poldhu at Bangor, Newcastle and Teddington during November and December is quite marked (Fig. 7). As the time of transmission during this period was from one to two hours after sunrise at Poldhu, this may be attributed to a persistence of " night effect," being additional to the evidence furnished in Table No. 19.

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(*e*) In the diagrams under consideration there is no similarity in the curves of variation either of the same transmitting station at the different receiving stations or of different transmitting stations at the same receiving station (excepting the effect noted in (*d*)).

The very much greater frequency and magnitude of the variations observed at Bangor is somewhat remarkable, and is possibly

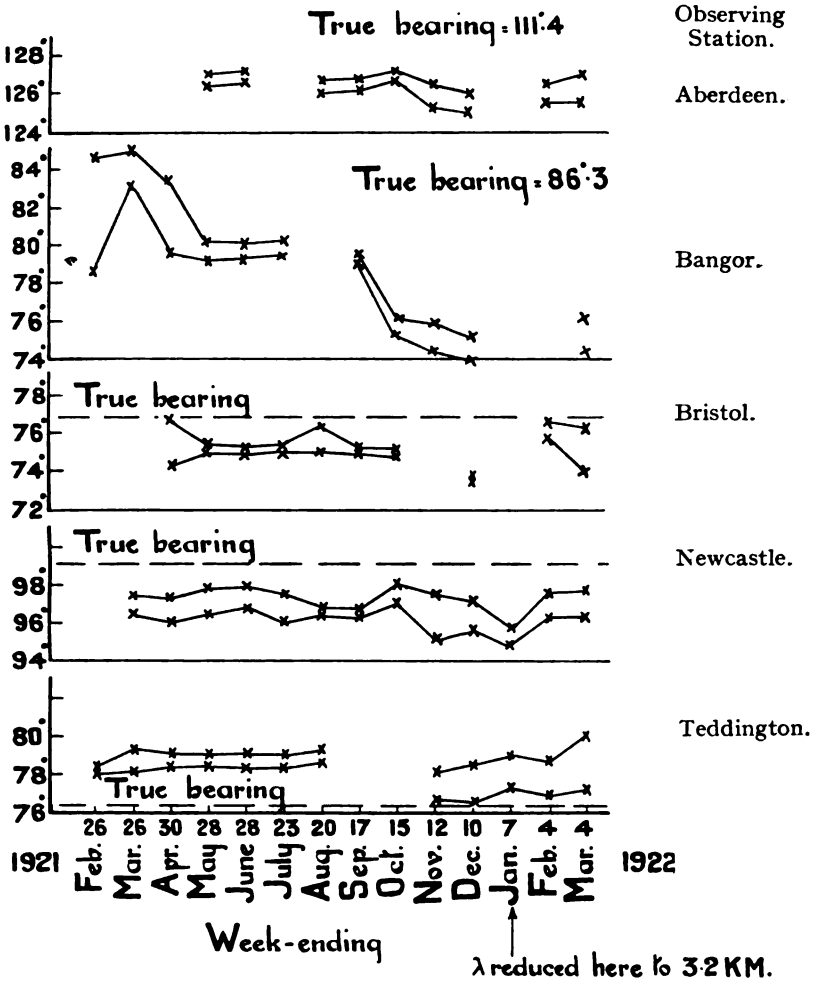

FIG. 6.—GRAPHS OF WEEKLY EXTREME BEARINGS OF NAUEN (DAMPED WAVES, $\lambda = 3{\cdot}9$ KM.) AT THE NOON TRANSMISSIONS.

due to varying local conditions, which may account for the " permanent " errors referred to in (7) (*b*) above. The most noticeable effects are the sudden changes in the bearings of Nauen from March to May and from September to October (Fig. 6), giving a total change in the mean day bearing of Nauen of nearly 10°.

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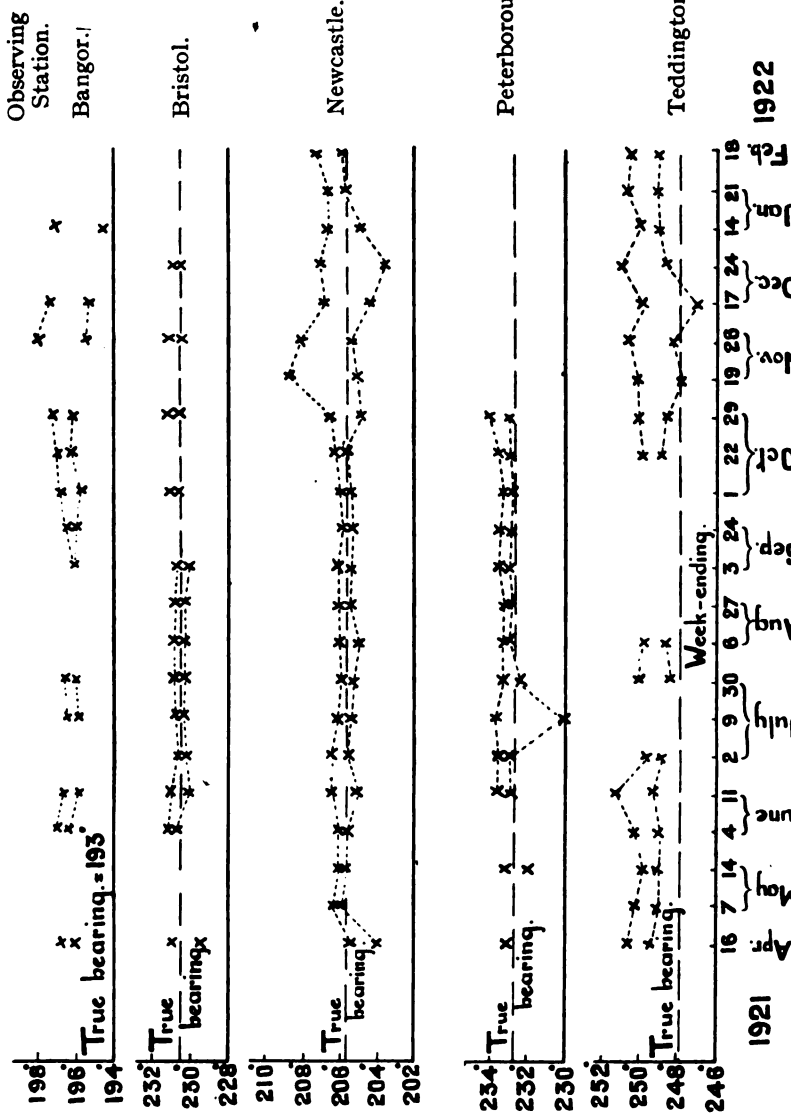

FIG. 7.—GRAPHS OF WEEKLY EXTREME BEARINGS OF POLDHU (DAMPED WAVES, $\lambda = 2{\cdot}8$ KM.) AT THE 09.30 TRANSMISSIONS.

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These were not accompanied by any similar changes in the bearings of Paris and Horsea, during the same weeks (Figs. 5 and 8). The gradual increase in the bearings of Horsea from February to April was accompanied by a fluctuation but not a steady change in the bearings of Nauen at the same period. The bearings of Paris, on the other hand, remained comparatively constant during this time, but they were subject to changes later (December to February).

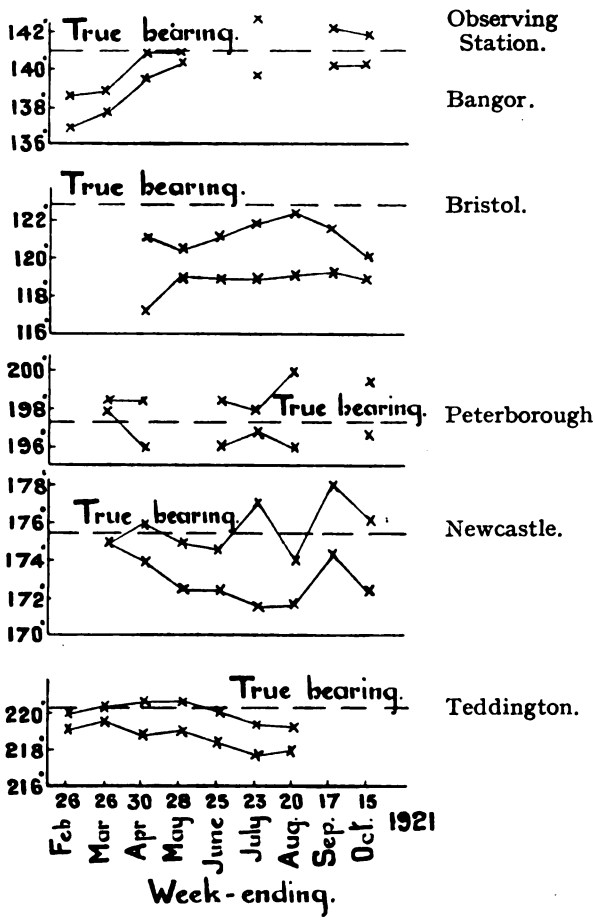

FIG. 8.—GRAPHS OF WEEKLY EXTREME BEARINGS OF HORSEA (UNDAMPED WAVES, $\lambda = 4 \cdot 5$ KM.) AT THE NOON TRANSMISSIONS.

(These observations were made without the use of Heterodyne Reception.)

Quite apart from the variations discussed, many of the curves under consideration, and especially those in Figs. 4, 6, and 7, demonstrate in a striking manner the great constancy of regular observed bearings for certain periods extending over several weeks, or even months. In many of the cases included, several hundred

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observations have been made during from two to six months with an extreme variation from the mean of less than 1°. This provides an experimental confirmation of the conclusions arrived at in Section I, that these direction-finding installations operated by a trained observer under favourable conditions give observed bearings which are reliable to within 1°. With the exception possibly of a few cases in which the observer has made a mistake

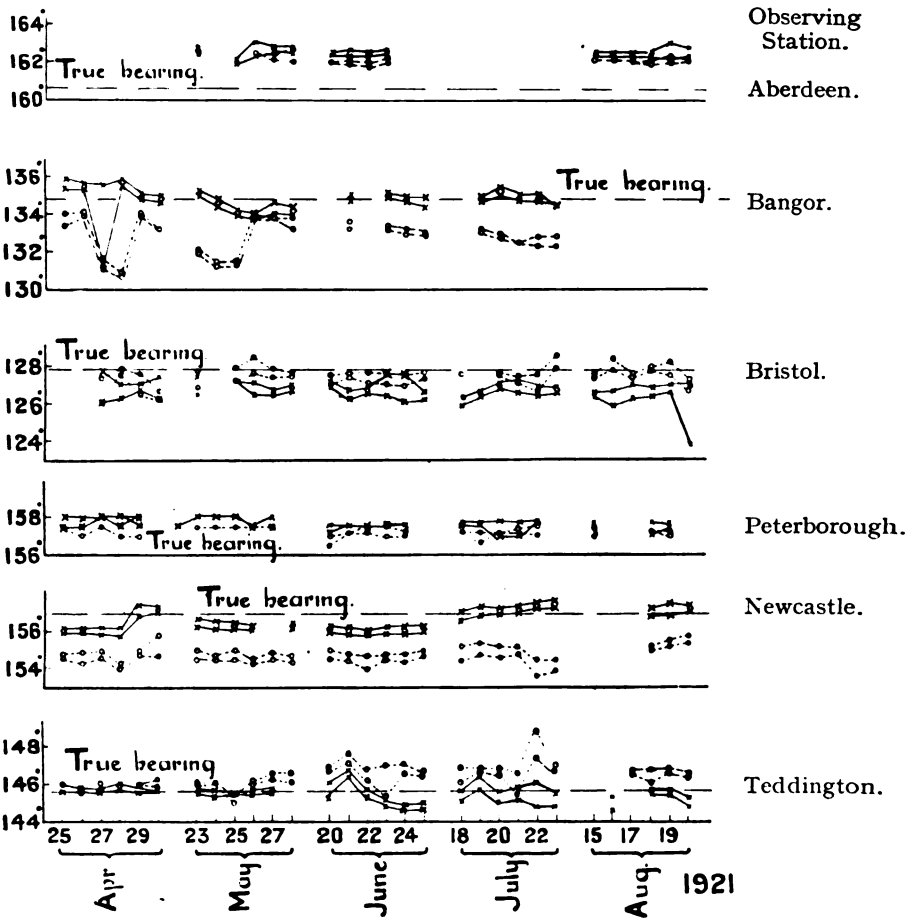

FIG. 9.—GRAPHS OF DAILY EXTREME BEARINGS OF PARIS.
(Damped Waves : — x — λ = 3·2 km. at 11.00—11.30.
-- o -- λ = 2·6 km. at 11.30—11.50.

in reading or recording the bearing, the errors of greater magnitude must, therefore, be taken as definite daytime variations, caused by some external influence, and these variations are discussed in greater detail in the succeeding sub-section.

A further point demonstrated by the curves in Figs. 3 to 8 is that the apparent variations observed are of the same order

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for signals received direct from over the sea, *e.g.*, Nauen to Aberdeen, as for the same signals received at an inland station. In a similar manner the variations on signals arriving over sea from Europe are of the same order as those taken on signals transmitted entirely overland.

(11) *Daily variation curves*

In Figs. 9 to 14 portions of the previous Figs. 5 to 8, are given in greater detail, to show the extreme bearings observed

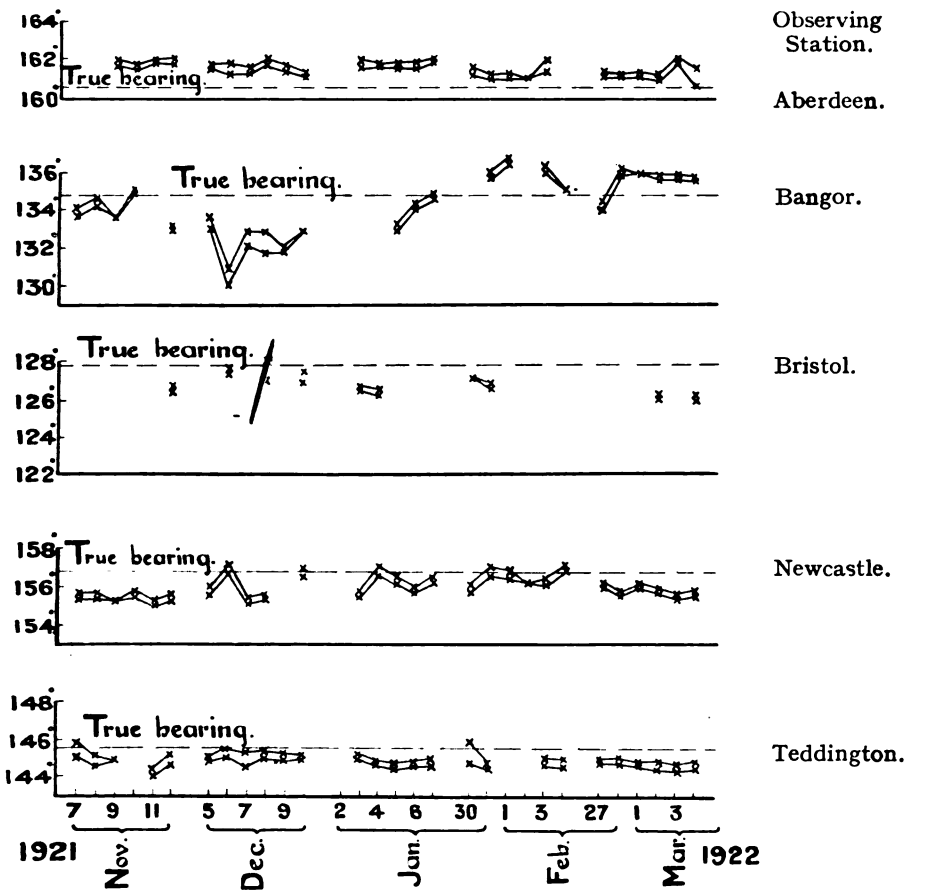

FIG. 10.—GRAPHS OF DAILY EXTREME BEARINGS OF PARIS (DAMPED WAVES, $\lambda = 3{\cdot}2$ KM.) AT THE 12.00—12.30 TRANSMISSION.

from day to day at the times given. In Figs. 9, 11 and 14 are shown the extremes of an average of five or six daily readings of the bearings of Paris, Nauen and Horsea respectively, equally spaced over half an hour's transmission during the same periods of observation. These diagrams indicate that over this period

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the observed bearings on any one day usually vary by only a fraction of a degree, a total variation of more than 1° being comparatively rare. On the other hand, the readings taken from one day to the next frequently show sudden changes of 1° or 2° and on some occasions greater amounts. These facts tend to show the improbability of instrumental errors being the cause of these variations, since such errors would be as likely to occur from one observation to the next as from one day to the next.

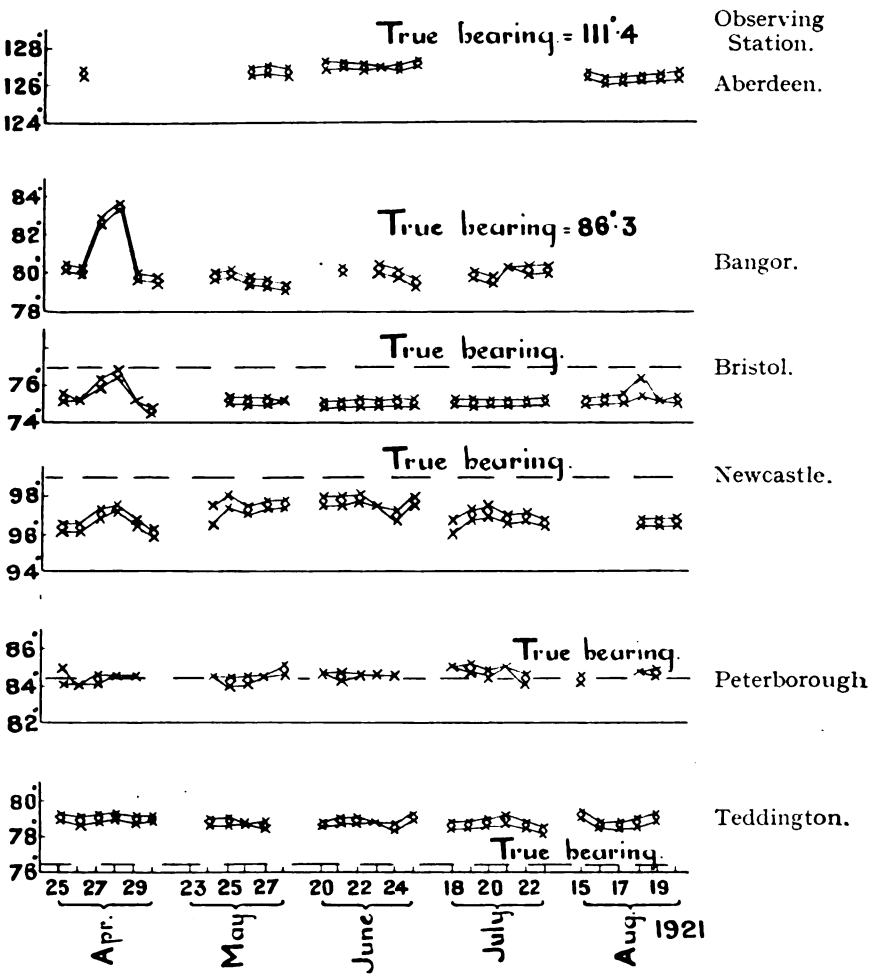

FIG. 11.—GRAPHS OF DAILY EXTREME BEARINGS OF NAUEN (DAMPED WAVES, $\lambda = 3{\cdot}9$ KM.) AT THE NOON TRANSMISSIONS.

Concerning what may, therefore, be termed "day variations," the following points may be enumerated as deduced from the above diagrams :—

(*a*) The various stations observing the same transmitting station display no similarity in their variations. The

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sole exception to this is found in Fig. 11, with the observations on Nauen at Bangor, Bristol and Newcastle during April, 1921 ; and even in this case the corresponding effects at Peterborough and Teddington were not noticed.

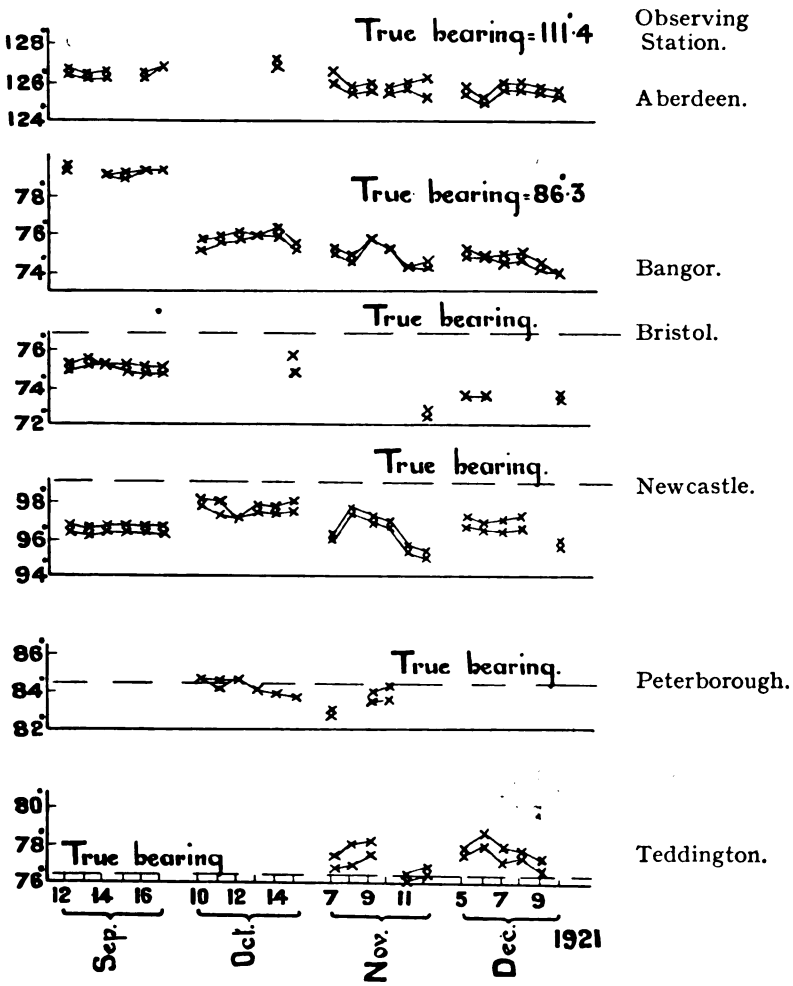

FIG. 12.—GRAPHS OF DAILY EXTREME BEARINGS OF NAUEN (DAMPED WAVES, $\lambda = 3{\cdot}9$ KM.) AT THE NOON TRANSMISSIONS.

(*b*) The bearings of different transmitting stations at any one observing station do not vary similarly from day to day. In Fig. 9 several examples are shown of the two wave-lengths of Paris giving different effects on the same day.

Confirmation of these points is given in the curves in Figs. 10 and 12, in which the sudden changes at Bangor are seen to be

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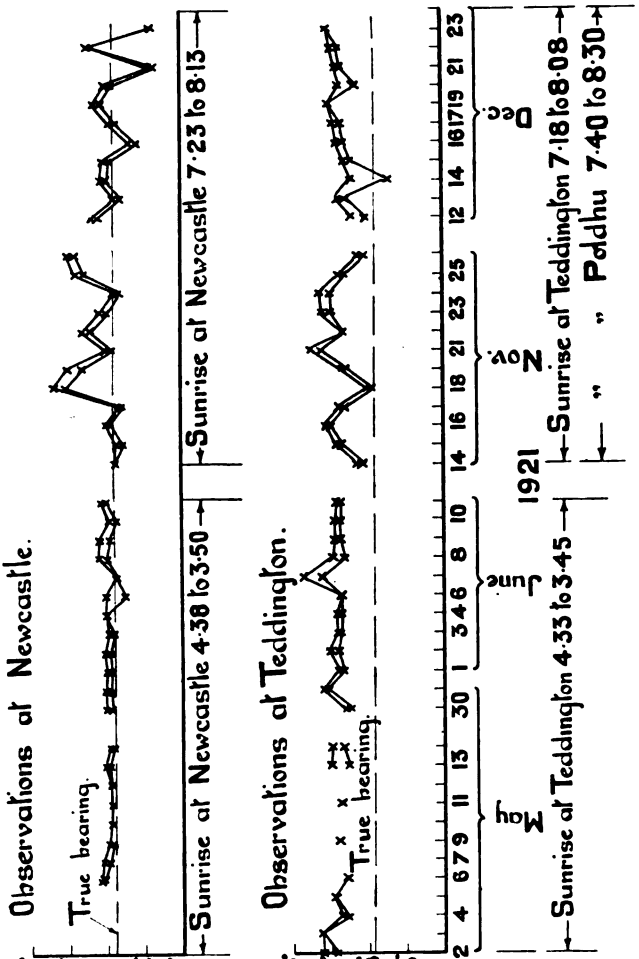

FIG. 13.—GRAPHS OF DAILY EXTREME BEARINGS OF POLDHU (DAMPED WAVES, $\lambda = 2{\cdot}8$ KM.) AT THE 09.30 TRANSMISSIONS.

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day-to-day effects and unaccompanied by corresponding changes elsewhere. In Fig. 13 the daily extreme bearings of Poldhu are given for two periods in summer and winter respectively, the variations in the latter period being possibly due to a persistence of " night effect " for about an hour after sunrise.

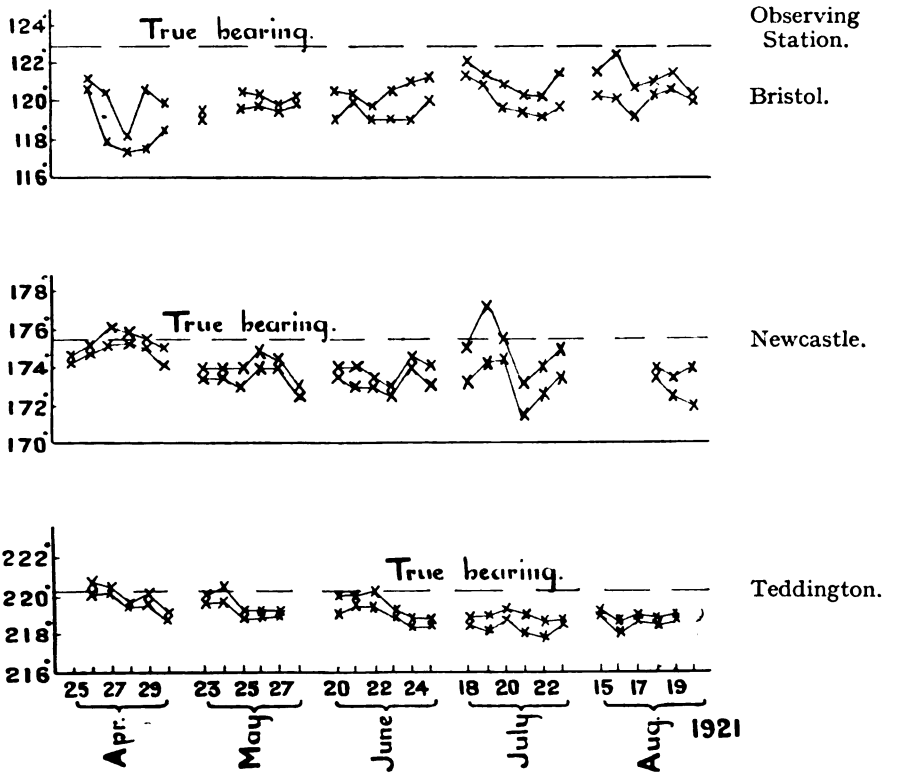

FIG. 14.—GRAPHS OF DAILY EXTREME BEARINGS OF HORSEA (UNDAMPED WAVES, $\lambda = 4{\cdot}5$ KM.) AT THE NOON TRANSMISSIONS.
(These observations were made without the use of Heterodyne Reception.)

In Figs. 15 and 16 the results are plotted for various observations made simultaneously at Slough and Teddington, two stations situated only 10 miles apart. In a few cases (*e.g.*, Karlsborg, Fig. 16) there appears to be similarity in the variations occurring from day to day, but in the majority of cases the changes are quite independent at the two stations.

(12) *General conclusions on day variations*

The results detailed and discussed in this section, representing many thousands of readings by several independent observers, appear to establish definitely the existence of small but appreciable variations in observed bearings of transmitting stations at times which are spaced several hours from either sunrise or sunset. These " day variations " take place slowly, there being no noticeable change during a half-hour's observation, and they are most

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clearly shown up by successive daily readings. The variations, moreover, appear to be entirely local to each observing station, although on some comparatively rare occasions the " local " area includes two or more receiving stations at distances apart exceeding one hundred miles.

These conclusions support the view that the day variations are due to some local influence, such as trees and mountains, the

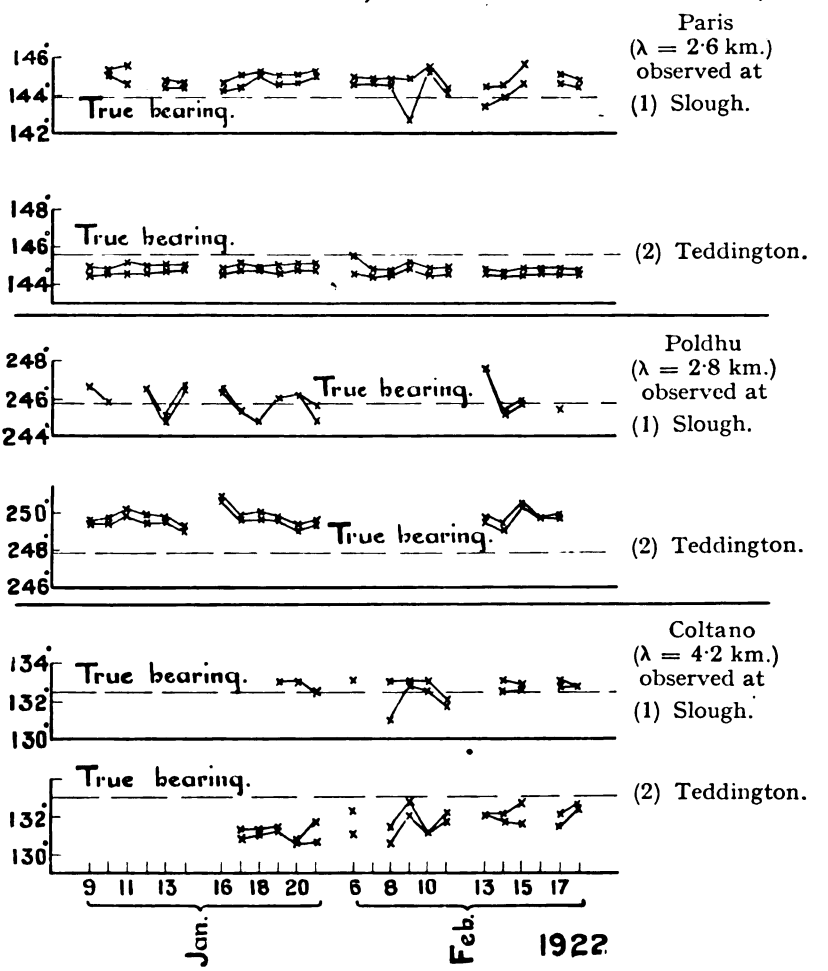

FIG. 15.—GRAPHS OF DAILY EXTREME BEARINGS TAKEN SIMULTANEOUSLY AT SLOUGH AND TEDDINGTON.
(Morning observations only.)

effects of which are subject to modification from day to day, possibly by meteorological changes. For example, at Teddington the permanent deviations of the day mean bearings could be ascribed to the surrounding trees, whose influence might easily vary after heavy rain. On this view, however, a much more definite seasonal variation might be anticipated than was actually observed.

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On a good site such as that at Newcastle, it is difficult to find an explanation of the variations or of the permanent deviations of the mean day bearings, but it seems very probable that these are due to the same cause. This fact again emphasises the great care which it is necessary to exercise in the selection of sites for direction-finding installations, and also shows the need for still further research on the effect of local conditions on these installations.

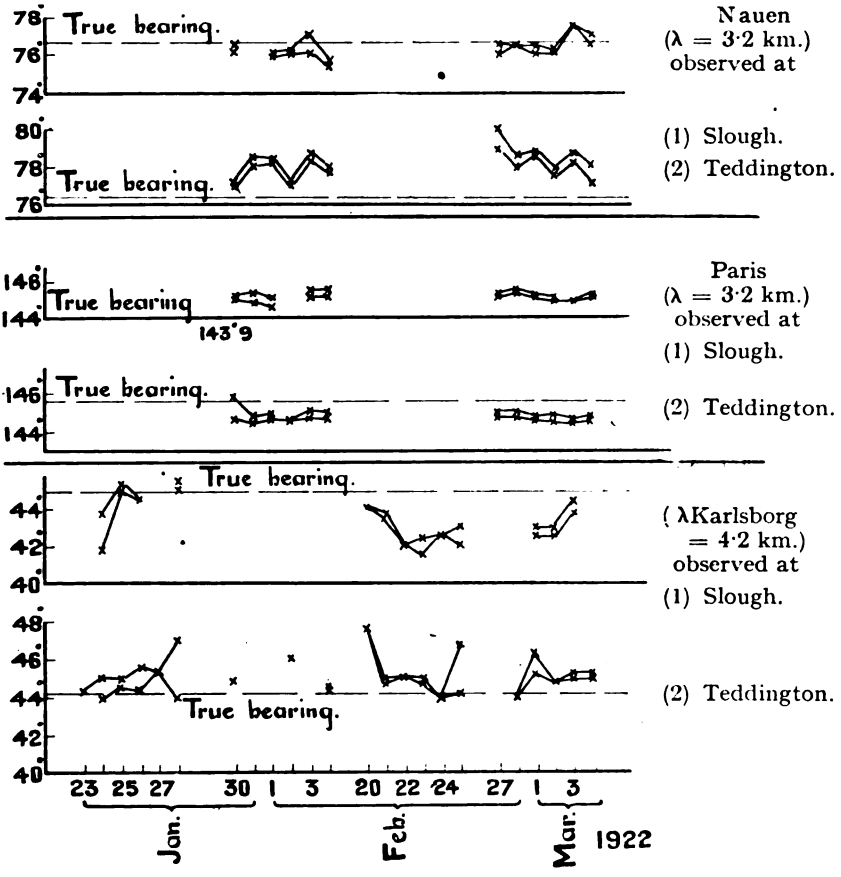

FIG. 16.—GRAPHS OF DAILY EXTREME BEARINGS TAKEN SIMULTANEOUSLY AT SLOUGH AND TEDDINGTON.
(Morning observations only.)

SECTION IV.—DISCUSSION OF RESULTS—NIGHT OBSERVATIONS

(13) *Systematic error of the mean bearings at night*

IN attempting to deduce some sort of order from the apparently chaotic variations of bearings observed at all stations during the night periods, a number of possible causes and effects have been investigated, each of which will be treated in turn.

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A general survey of the summary of the observations taken in the evening periods, as recorded in Tables 5 to 14, shows that the apparent bearings of different transmitting stations during these periods vary over a range which sometimes exceeds 60°. In spite of this large variation, however, it is very noticeable that the mean bearings differ by quite small amounts from the corresponding mean bearings for the day periods. This difference between the day and night means may be termed the systematic error of the night observations, and the following Table No. 20 gives a *résumé* of these errors for the cases in which 50 or more observations were made in both day and night periods. It is not considered that a smaller number of observations gives a fair average reading for comparison.

TABLE NO. 20.—SHOWING THE SYSTEMATIC ERROR OF NIGHT OBSERVATIONS

Observing Station.	Transmitting Station.	Systematic error (*i.e.*, difference, night mean —day mean).	Total night variation.
		(degrees)	(degrees)
Aberdeen ..	Aberdeen ..	− 0·5	1·8
,, ..	Paris	0·0	4·0
,, ..	Poldhu	+ 0·5	8·7
Bangor ..	Clifden	+ 2·8	64·7
,, ..	Horsea	+ 1·0	25·5
,, ..	Karlsborg ..	+ 0·4	22·1
,, ..	Paris	+ 0·7	26·5
,, ..	Poldhu	+ 1·3	18·0
Bristol ..	Aranjuez ..	− 0·2	11·6
,, ..	Chelmsford ..	+ 0·5	17·0
,, ..	Horsea	+ 0·3	13·5
,, ..	Paris	+ 0·5	17·4
,, ..	Poldhu	− 2·1	57·5
Newcastle ..	Aranjuez ..	− 0·4	5·6
,, ..	Chelmsford ..	+ 0·1	4·0
,, ..	Cleethorpes ..	+ 0·7	12·0
,, ..	Clifden	+ 0·2	33·0
,, ..	Horsea	+ 0·4	14·5
,, ..	Karlsborg ..	+ 1·9	23·0
,, ..	Nicolaieff ..	+ 1·7	12·8
,, ..	Paris	+ 0·2	8·5
,, ..	Poldhu	− 1·3	32·5
Peterborough	Horsea	+ 0·2	20·0
,,	Paris	− 0·5	7·7
,,	Poldhu	− 1·7	22·0
Slough ..	Chelmsford ..	− 0·9	14·6
,, ..	Karlsborg ..	− 1·9	23·0
,, ..	Paris	+ 0·2	5·4
,, ..	Poldhu	− 5·1*	9·2
Teddington	Budapest ..	+ 1·1	19·3
,, ..	Chelmsford ..	− 0·2	14·6
,, ..	Coltano	+ 1·8	20·7
,, ..	Horsea	+ 0·1	8·3
,, ..	Karlsborg ..	− 1·9	23·6
,, ..	Paris (FL) ..	− 0·1	6·3
,, ..	Paris (UFP) ..	+ 0·3	22·3
,, ..	Poldhu	− 3·1	38·3

* Less than 50 readings, but inserted for comparison with Teddington.

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It will be seen that in the majority of cases the systematic error is small, and almost negligible compared with the large variations recorded. In a few instances, however, notably Karlsborg and Poldhu, there is a definite systematic error at several receiving stations, and, as shown in the further table (No. 21) below, there is a noticeable similarity in the sign and order of magnitude of this error for stations on approximately the same great circle from the transmitter.

TABLE No. 21.—COMPARISON OF SYSTEMATIC ERROR WITH TRUE BEARINGS

Transmitting station.	Observing station.	True bearing.	Systematic night error.
		(degrees)	(degrees)
Poldhu	Bangor	193	+ 1·3
,, ...	Aberdeen	196	+ 0·5
,, ...	Newcastle	205	− 1·3
,, ...	Bristol	231	− 2·1
,, ...	Peterborough ..	232	− 1·7
,, ...	Slough	246	− 5·1
,, ...	Teddington ..	248	− 3·1
Karlsborg	Slough	46	− 1·9
,, ...	Teddington ..	46	− 1·9
,, ...	Bangor	55	+ 0·4
,, ...	Newcastle	62	+ 1·9

These results would appear to show that for Karlsborg and Poldhu the systematic night error becomes zero for receiving stations situated on great circles corresponding to bearings of approximately 50° and 200° respectively on these two transmitters. For stations on either side of these great circles the bearings tend to be displaced in opposite directions at night. More results are required to confirm these conclusions and pursue them in any further detail.

(14) *Magnitude of night variations*

The magnitude of the variations in observed bearings is widely distributed among the transmitting and receiving stations, and in Table No. 22 the two largest variations recorded at each receiving station are extracted for comparison.

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TABLE NO. 22.—SHOWING THE TWO LARGEST VARIATIONS RECORDED AT EACH OBSERVING STATION

Observing station.	Transmitting station.	Variation.
		(degrees)
Aberdeen	Karlsborg	66·0
,, ...	Moscow	15·6
Bangor	Clifden	64·7
,, ...	Chelmsford	46·1
Belfast*	Karlsborg	22·8
,, ...	Moscow	18·0
Bristol	Poldhu	57·5
,, ...	Karlsborg	47·7
Cambridge*	Karlsborg	38·5
,, ...	Poldhu	23·0
Leeds*	Karlsborg	14·0
,, ...	Moscow	11·0
Newcastle	Karlsborg	37·0
,, ...	Moscow	34·0
Peterborough	Karlsborg	30·0
,, ...	Sofia	24·0
Slough*	Karlsborg	23·0
,, ...	Moscow	18·0
Teddington	Moscow	44·5
,, ...	Poldhu	38·3

* Station not observing for whole period.

This Table shows that while extreme variations are most prevalent in observing upon Karlsborg and Moscow transmitting stations over distances of the order of 700 and 1,500 miles respectively, excessive variations also frequently occur with Poldhu at distances down to 150 miles. While frequency of observation may have some effect upon the maximum variations recorded, this does not hold in many cases in which hundreds of observations have been made in the evening periods, showing only small or medium variations. It is also to be noted that the variations experienced were usually more acute at Bangor than elsewhere, possibly due to the mountainous nature of the country surrounding this station.

(15) *Relation of variations with the direction of transmission*

With a view to ascertaining if there is any relation between the direction of transmission of signals over the earth's surface and the magnitude of the variations observed, graphs have been plotted for the different receiving stations. Owing to the similarity of the general form of these, all the results have been superimposed in one diagram, given in Fig. 17, in which no distinction is made for the different places of observation, but in which the results obtained on transmitting stations in the British Isles are specially marked.

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Although there are many large discrepancies, the results plotted in Fig. 17 suggest a fairly definite curve connecting the extent of variation with the direction of transmission, the maximum effects being in the approximate directions 60° and 240°, while the minimum variations occur at about 160° and 340°. Some caution is needed in interpreting the curve, for, since the true bearings of the more distant European stations are sensibly

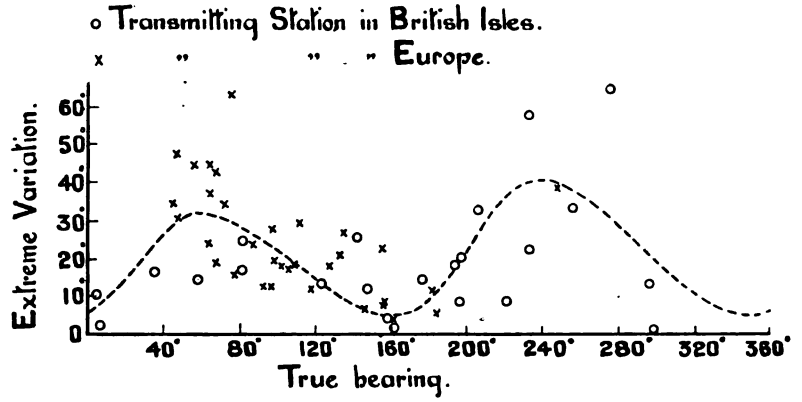

FIG. 17.—SHOWING EXTENT OF NIGHT VARIATIONS AGAINST TRUE BEARINGS OF ALL TRANSMITTING STATIONS OBSERVED AT ABERDEEN, BANGOR, BRISTOL, NEWCASTLE, PETERBOROUGH, AND TEDDINGTON.

the same all over the British Isles, the diagram may only represent some characteristic of the various transmitting aerials. An indication of this is provided in the observations at Teddington on the two stations at Paris (FL and UFP), on whose transmissions variations of 6·3° and 22·3° respectively were recorded during the same evening periods. The comparison is not quite a strict one,

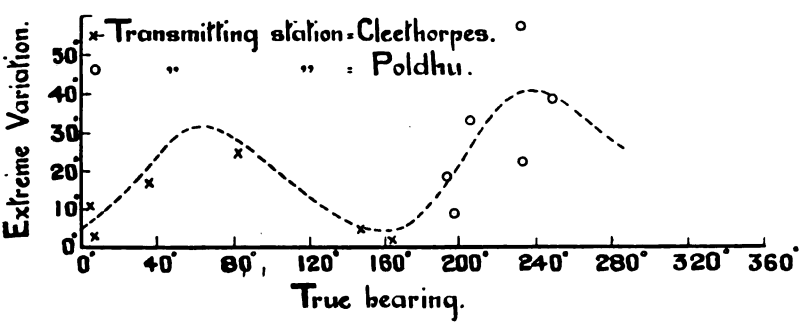

FIG. 18.—SHOWING RELATION OF NIGHT VARIATIONS TO TRUE BEARINGS OF CLEETHORPES AND POLDHU, OBSERVED AT ABERDEEN, BANGOR, BRISTOL, NEWCASTLE, PETERBOROUGH, AND TEDDINGTON.

since damped waves were used in one case and undamped waves in the other, but future results should confirm or negative this observation.

The best test of the effect of the direction of transmission upon the extent of variation is obviously to observe the same transmitting station in different directions and at the same distance

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from it. Although the last condition is not complied with, some of the readings taken on transmitters in the British Isles in different directions aid in this matter. In Fig. 18 the variations recorded on two stations only, Cleethorpes and Poldhu, are plotted in their relation to the direction of reception, as before. Although these points are few and scattered, there is the suggestion of a curve of the same shape as that given in Fig. 18. While more confirmatory evidence is needed, these two figures seem to indicate the possibility of the variations in apparent observed bearings on a radio direction finder being a minimum for a direction of transmission which approximates more nearly to the magnetic than to the geographical meridian.

(16) *Dependence of variations upon wave-length*

The general summary of results contained in Tables 5 to 14 does not show any systematic relation between the extent of variation of the observed bearings, and the wave-length of transmission. The range of wave-lengths covered by these observations is from 2·0 to 6·0 km., and some of the largest variations recorded were experienced on waves near each of these extremes viz., Karlsborg, 2·5 km., and Clifden, 5·8 km. The observations obtained on the two wave-lengths of Nantes (2·4 and 4·2 km.) also do not show any consistent difference.

On account of the almost continuous variations in apparent bearings taking place during night periods, this point can only strictly be investigated by almost instantaneous changes in the wave-length, and the opportunity for making these observations is, therefore, rare. A point which has been frequently observed, however, at most stations is that, when the wave-length of Karlsborg's transmission is changed from 4·2 to 2·5 km. with an interval of a few minutes, the observed bearing changes by amounts ranging up to 10°. The change produced is not always in the same direction, nor does it always coincide with the general drift of the apparent bearing before the change in wave-length.

On certain occasions it has been observed that one or two spark stations show two distinct resonance peaks on the tuning condenser of the direction-finding coil receiver. This has been attributed to the emission of a double wave due to too close a coupling at the transmitter. The effect has been chiefly observed on Coltano at Belfast, Newcastle, Slough and Teddington, the 4·2 km. wave from this station developing two peaks at about 4·0 and 4·3 km. The two waves so received gave bearings which agreed to within 1° in the daytime, but at night, and particularly when variations are occurring, the observed bearings on the two waves differ by amounts ranging up to 3° or 4°. Similar effects have been observed at Teddington on Nantes and Karlsborg, although on less frequent occasions.

This somewhat scanty evidence, therefore, indicates that when night variations are present a comparatively small change in wave-length may produce differences of several degrees in the

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apparent bearings observed. These differences are, however, only temporary, and the systematic error of a number of observations remains practically independent of wave-length.

(17) *Weekly variation curves*

To investigate the manner of the variation of apparent bearings with time the same principle is adopted as in the previous section, viz., the graphical representation of the extreme bearings for weekly and daily periods.

In Figs. 19–21 graphs are given illustrating the annual fluctuation of the extreme bearings during a week's observations

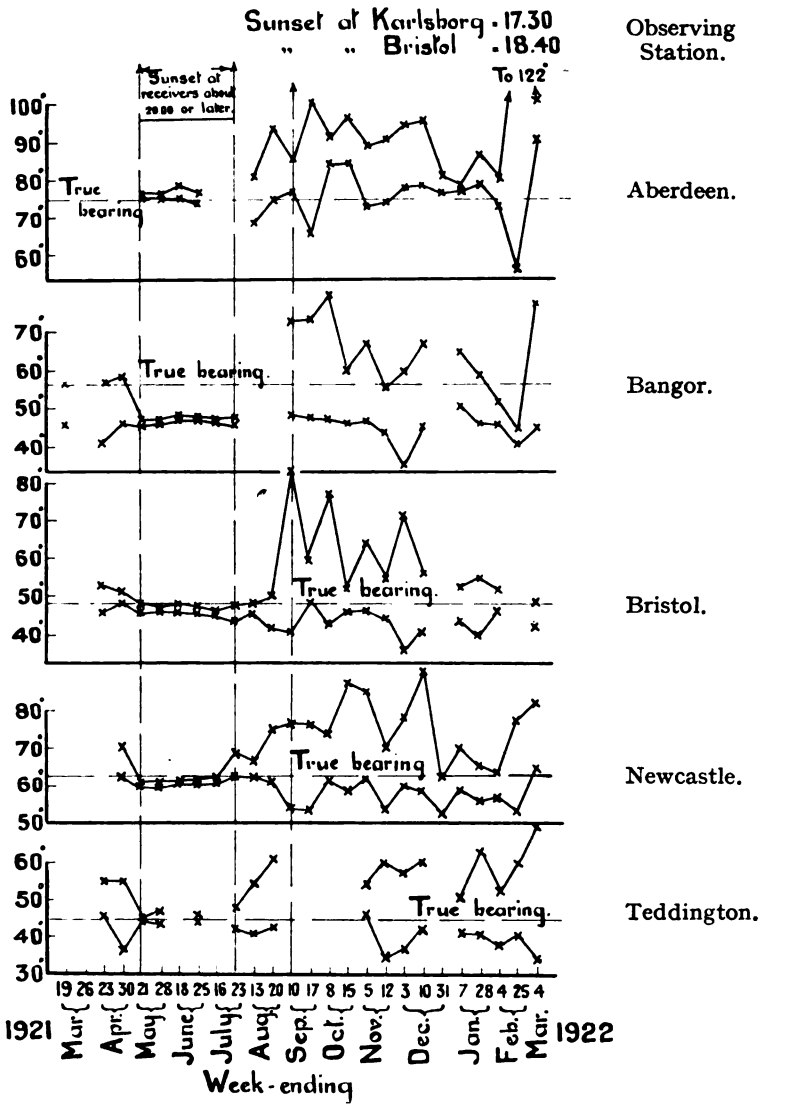
Sunset at Karlsborg - 17.30
" " Bristol - 18.40
Observing Station.
Sunset at receivers about 2030 or later
To 122°
True bearing
Aberdeen.
Bangor.
Bristol.
Newcastle.
Teddington.
19 26 23 30 21 28 18 25 16 23 13 20 10 17 8 15 5 12 3 10 31 7 28 4 25 4
1921 Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec. Jan. Feb. Mar. 1922
Week-ending

FIG. 19.—GRAPHS OF WEEKLY EXTREME BEARINGS OF KARLSBORG (DAMPED WAVES, $\lambda = 2{\cdot}5$ KM.) AT THE 20.00 TRANSMISSIONS.

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on three transmitting stations at various receiving stations during the period 20.00–22.00 G.M.T. Further graphs for other

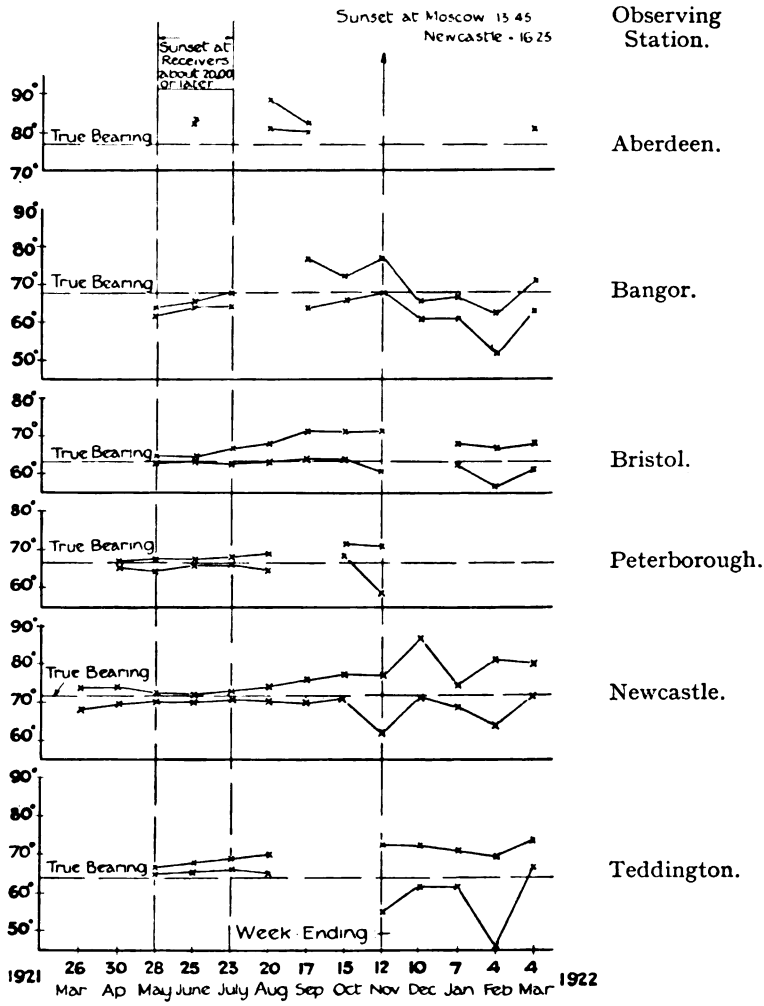
Sunset at Moscow 15 45
Newcastle - 16 25
Sunset at Receivers about 20.00 or later
Observing Station.
True Bearing
Aberdeen.
Bangor.
Bristol.
Peterborough.
Newcastle.
Teddington.
Week Ending
1921 26 Mar 30 Ap 28 May 25 June 23 July 20 Aug 17 Sep 15 Oct 12 Nov 10 Dec 7 Jan 4 Feb 4 Mar 1922

FIG. 20.—GRAPHS OF WEEKLY EXTREME BEARINGS OF MOSCOW (DAMPED WAVES, $\lambda = 4{\cdot}8$ KM.) AT 20.00 to 22.00 TRANSMISSIONS.

periods of observation are given in Figs. 22–24. The following points are immediately evident from these curves :—

(*a*) Up to nearly the time of sunset over the westerly end of the path of transmission of the signals, no serious variation of bearings occurs, these being constant to within 2° or 3°, as commonly observed in daylight.

(*b*) When the sun has set over the whole path of transmissions the observed bearings commence to wander in an erratic manner.

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(*c*) As the time of observation becomes later relative to sunset the magnitude of the variations increases considerably, reaching a maximum at about 1½ to 2 hours after total darkness.

(*d*) Apart from the above occurrences in the neighbourhood of sunset, there is apparently no seasonal or other fluctuation in the order of magnitude of the variations over the year, even though the time of observation may be several hours after sunset.

(*e*) In general, the effects referred to in (*a*)–(*d*) above occur simultaneously at the different observing stations distributed over the British Isles.

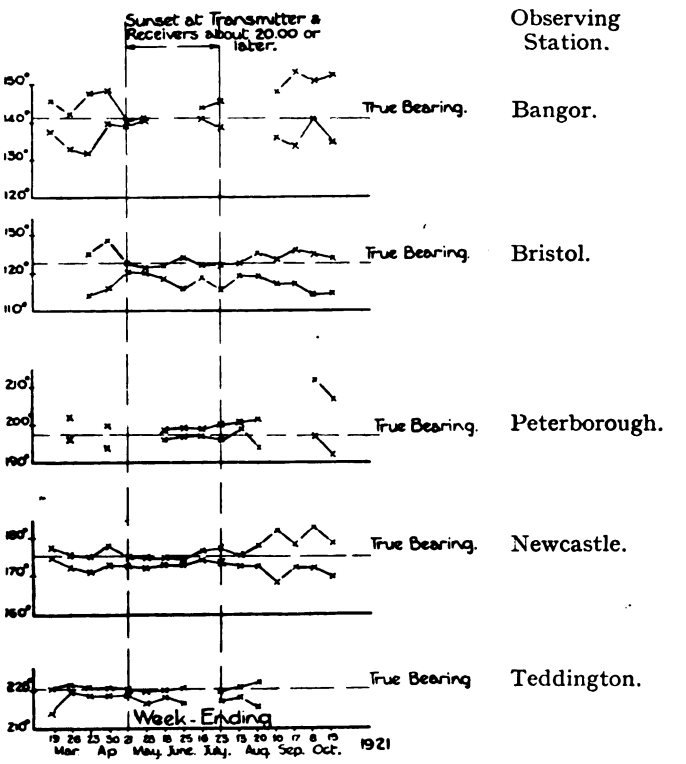

FIG. 21.—GRAPHS OF WEEKLY EXTREME BEARINGS OF HORSEA (UNDAMPED WAVES, $\lambda = 4{\cdot}5$ KM.) AT THE 20.00 TRANSMISSIONS.

(These observations were made without the use of Heterodyne Reception.)

The above deductions with regard to sunset cannot be established from the above curve to within a minute or so. Hence, in the case of observations on transmitting stations in the British Isles, *e.g.* Cleethorpes, Horsea and Poldhu, where sunset occurs at both transmitter and receiver within a few minutes, the exact variations in the transition period from daylight to darkness require more detailed investigation. At the more distant European transmitting stations, however, sunset takes place one or

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two hours before its occurrence in England, and there is thus ample time to study the effect on the transmission of electromagnetic waves in the transition period across the dividing belt between daylight and darkness. The general inference made in (*a*) and (*b*) above is that no effect upon the observed bearings takes place until this dividing belt passes the receiving station

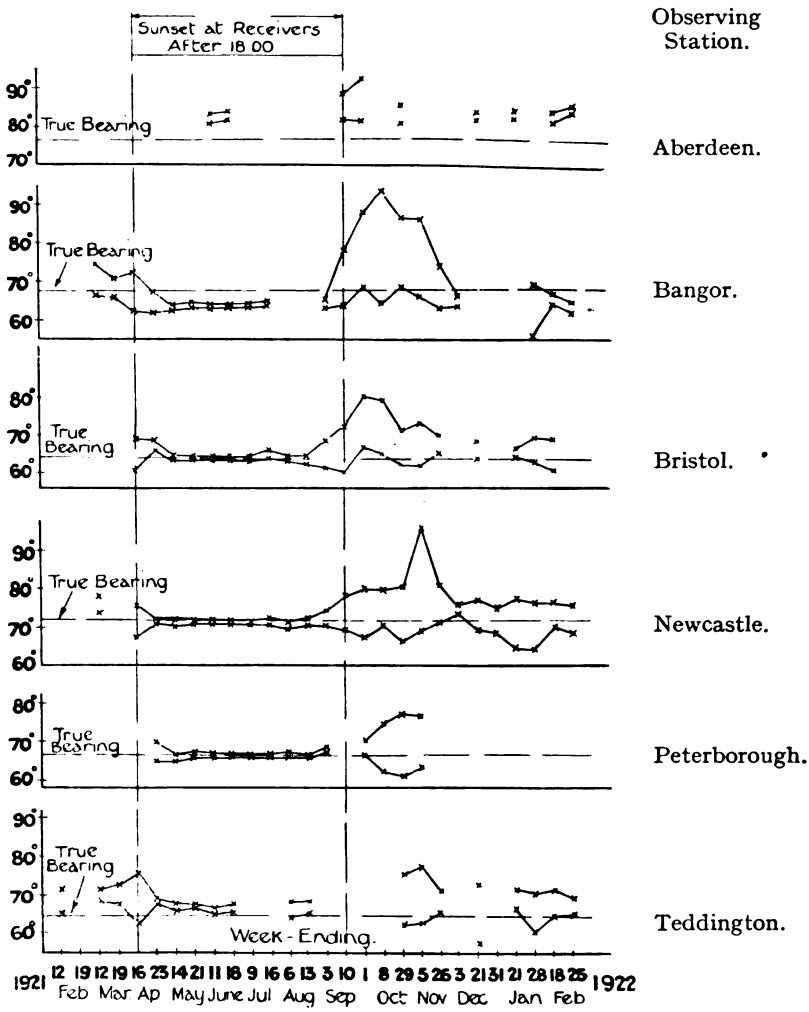
Sunset at Receivers After 18 00
Observing Station.
True Bearing
Aberdeen.
Bangor.
Bristol.
Newcastle.
Peterborough.
Teddington.
Week-Ending.
1921 12 19 12 19 16 23 14 21 11 18 9 16 6 13 3 10 1 8 29 5 26 3 21 31 21 28 18 25 1922
Feb Mar Ap May June Jul Aug Sep Oct Nov Dec Jan Feb

FIG. 22.—GRAPHS OF WEEKLY EXTREME BEARINGS OF MOSCOW (DAMPED WAVES, $\lambda = 4{\cdot}8$ KM.) AT 18.00 to 20.00 TRANSMISSIONS.

so that darkness prevails over the whole path of transmission. As a typical instance the observations on Karlsborg made during the week ending 25th June, 1921, may be quoted as given in Fig. 19. The time of sunset at Karlsborg was approximately 19.15 and at Bristol 20.25, being only a few minutes earlier or later at the other receiving stations. The observations were

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made from 20.00 to about 20.30, commencing, therefore, 45 minutes after sunset at Karlsborg and taking place during the passage of the dividing belt over the receivers, and the 24 readings taken at Bristol during the week under consideration showed an extreme difference of 2°.

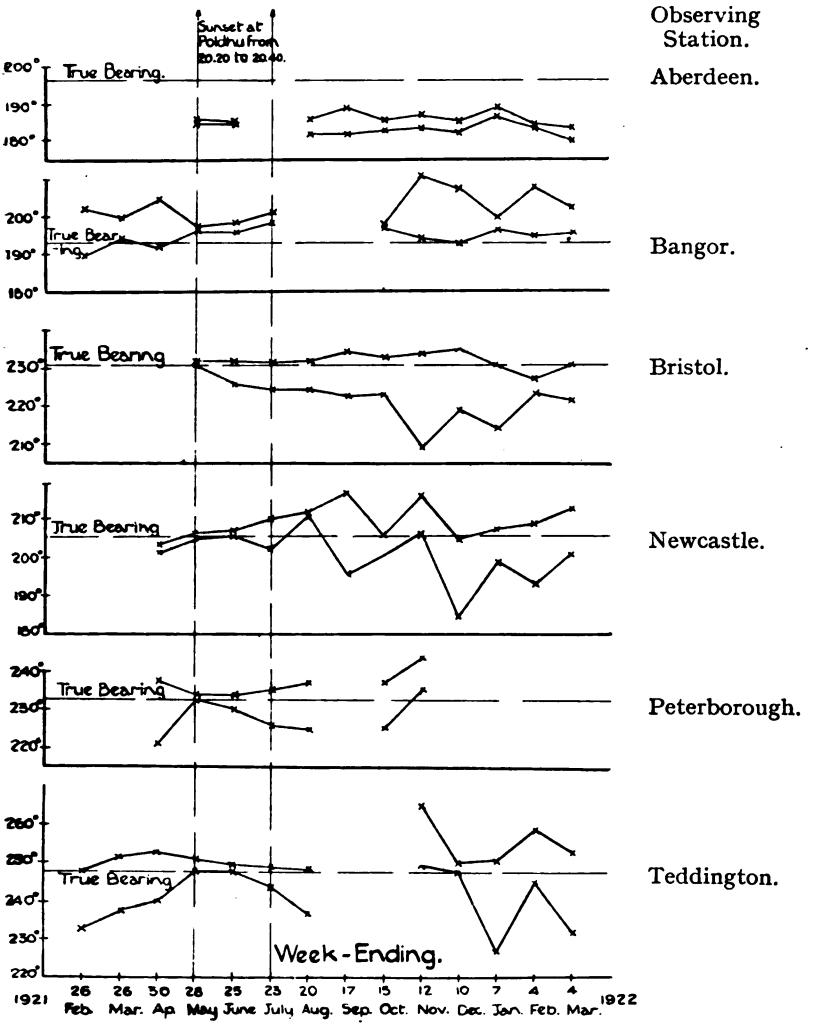

FIG. 23.—GRAPHS OF WEEKLY EXTREME BEARINGS OF POLDHU (DAMPED WAVES, $\lambda = 2{\cdot}8$ KM.) AT THE 21.30 TRANSMISSIONS.

About three months later (week ending 10th September, 1921) a similar set of observations showed a variation of 42·9° at about one and a half hours after sunset at Bristol.

During the same week and periods in June, sunset occurred at Moscow at 17.45, or two and a quarter hours before the commencement of observations, and yet the 42 readings taken on this station at Newcastle show a total variation of 1·5°. Five months

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later, *i.e.*, during week ending 12th November, 44 observations taken on Moscow at about two hours after sunset at Newcastle showed a variation of 14·5° (*see* Fig. 20).

It is somewhat unfortunate, but unavoidable, that the majority of the transmitting stations upon which regular observation has been maintained are situated to the east of the receiver, so that the transmission is in general from east to west. The results given in Fig. 21 for Horsea observed at Peterborough and Teddington, however, indicate that quite similar effects take place

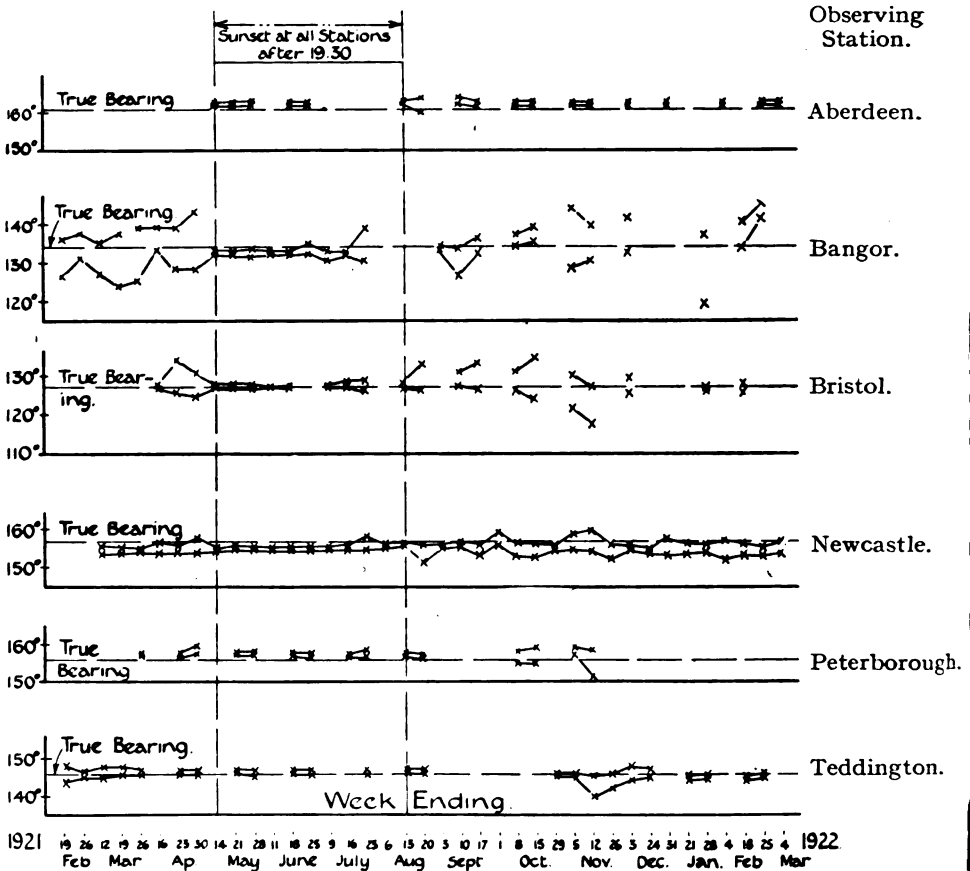

FIG. 24.—GRAPHS OF WEEKLY EXTREME BEARINGS OF PARIS (DAMPED WAVES, $\lambda = 2{\cdot}6$ KM.) AT 19.30 AND 21.10 TRANSMISSIONS.

when the transmission is towards the east as when it is to the west, as from Horsea to Bangor, Bristol and Newcastle. The range of transmission is somewhat short in these cases, and the transition effect less well-defined, but the curves given are all consistent with the previous conclusions. Similar confirmatory evidence for transmissions in a northerly and easterly direction are afforded by the results on Poldhu recorded in Fig. 23. Although

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in this case the latest sunset period occurred about one hour before the time of observation, there is a marked decrease of the extent of variations during this time. With the advance of the year and the consequent earlier sunset, the variations increase in magnitude to a certain extent, and then remain of the same order during the annual cycle, although during December the observations take place about four hours after sunset. Fig. 23 also provides an indication of the falling off of the extent of variation with increasing distance from the transmitter. For example, Aberdeen and Bangor are practically on the same great circle

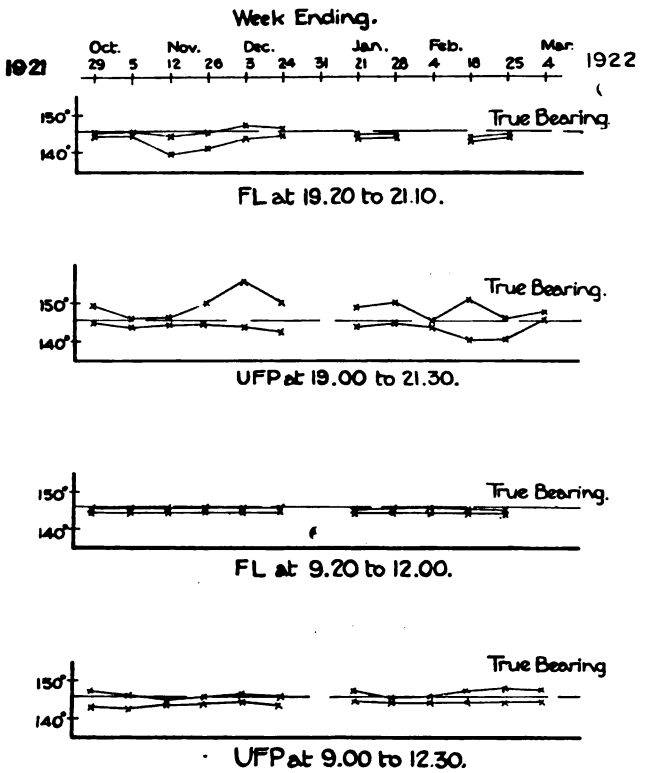

FIG. 25.—GRAPHS OF WEEKLY EXTREME BEARINGS OF TWO PARIS TRANSMITTING STATIONS OBSERVED AT TEDDINGTON DURING MORNING AND EVENING PERIODS.

(1) Paris (FL) : Damped waves, $\lambda = 2{\cdot}6$ km.
(2) Paris (UFP) : Undamped waves, $\lambda = 2{\cdot}4$ km.

from Poldhu, at distances from it of 509 and 228 miles respectively, and the total variations observed on the same transmissions at the two stations are 8·7° and 18·0° respectively. At Bristol, the nearest observing station to Poldhu (152 miles) the extent of variation was 26·0° during the same period.

The majority of the graphs in Figs. 19–23 display a marked asymmetry in the departures of the night bearings from the day

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mean, and well illustrate a systematic error of the mean night bearing as discussed in paragraph (13) above.

Apart from the points already referred to, these results do not display any great differences for the various observing stations, whether these be on the same or different great circles from the transmitter. In Fig. 24 the results of observations on the Paris (Eiffel Tower) station during the evening transmission are given,

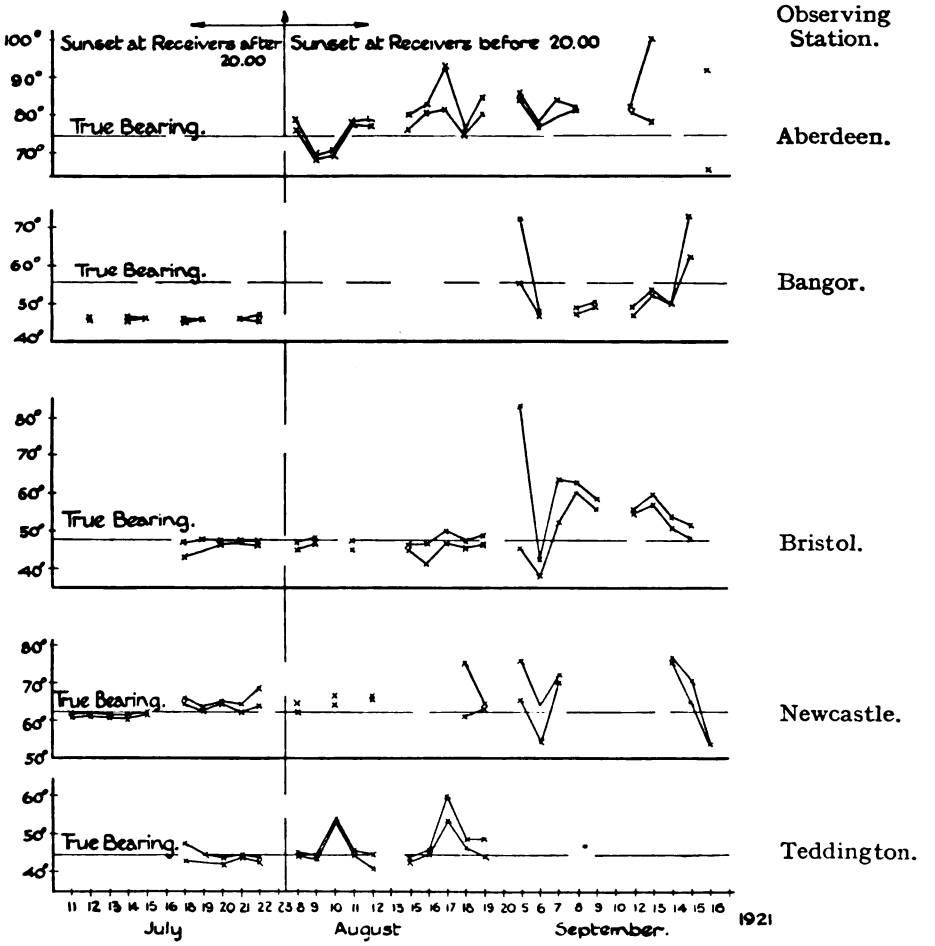

FIG. 26.—GRAPHS OF DAILY EXTREME BEARINGS OF KARLSBORG (DAMPED WAVES, $\lambda = 2{\cdot}5$ KM.) AT 20.00 TRANSMISSIONS.

and these indicate a variation of much less magnitude at stations corresponding to a bearing of 150° than at the stations at which the bearing is approxinately 130°. While this effect may be partly due to the different direction of transmission, as discussed in paragraph 15, it is not entirely independent of the transmitting stations. For, in Fig. 25, some of the results observed at Teddington on the Paris (Eiffel Tower) station are compared with

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those obtained during the same observation periods on Paris (Le Vallois), and the latter readings are seen to vary to a greater extent. The effect of the change from damped to undamped wave transmission is one remaining for future investigation.

(18) *Daily variation curves*

The extreme bearings recorded during some of the daily periods of observations on Karlsborg, Moscow and Poldhu at various stations are shown graphically in Figs. 26–30. In Fig. 26

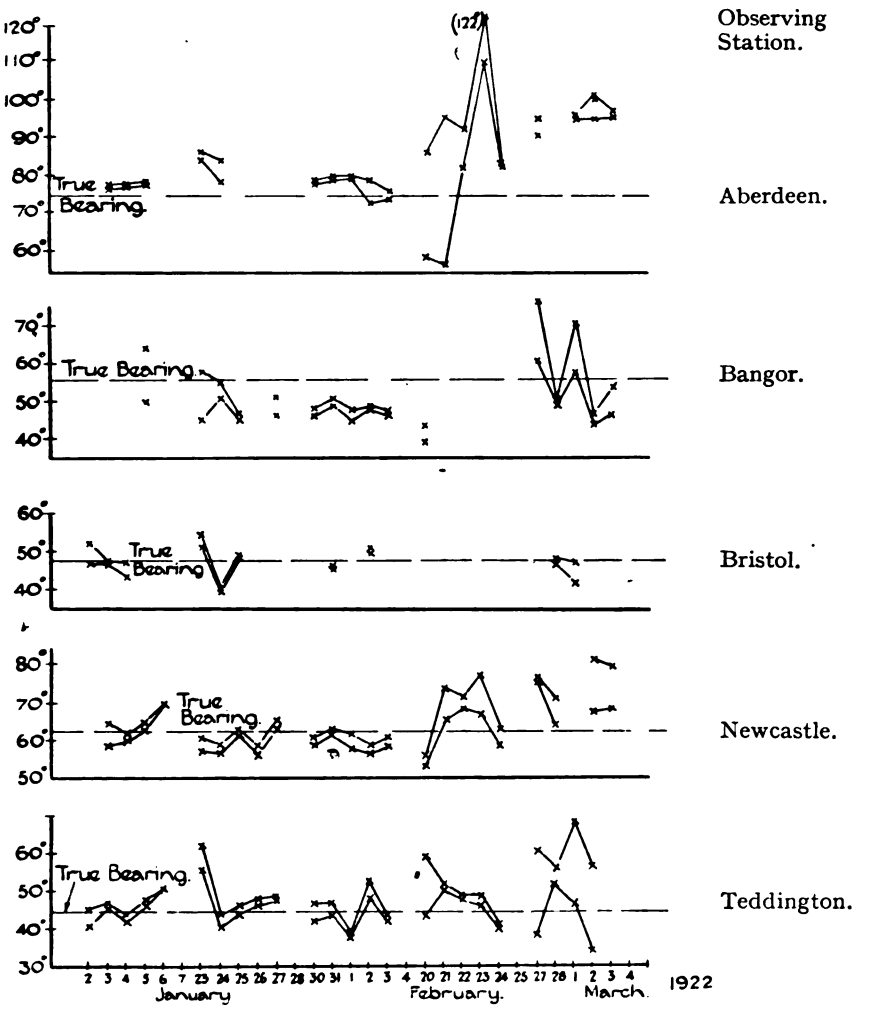

FIG. 27.—GRAPHS OF DAILY EXTREME BEARINGS OF KARLSBORG (DAMPED WAVES, $\lambda = 2{\cdot}5$ KM.) AT 20.00 TRANSMISSIONS.

the transition period of sunset at the receivers is illustrated in its effect upon the bearings of Karlsborg. The remaining curves

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show the manner of the nightly variations, and the chief effects may be summarised as follows :—

(*a*) During a period of observation extending from one-half to one hour, the apparent bearings vary in general by amounts of from 3° to 10°.

(*b*) Larger variations are sometimes recorded during a period ranging up to 38°.

(*c*) Quite frequently also, the variation from one night to the next is greater than the extreme variation during the period of observation.

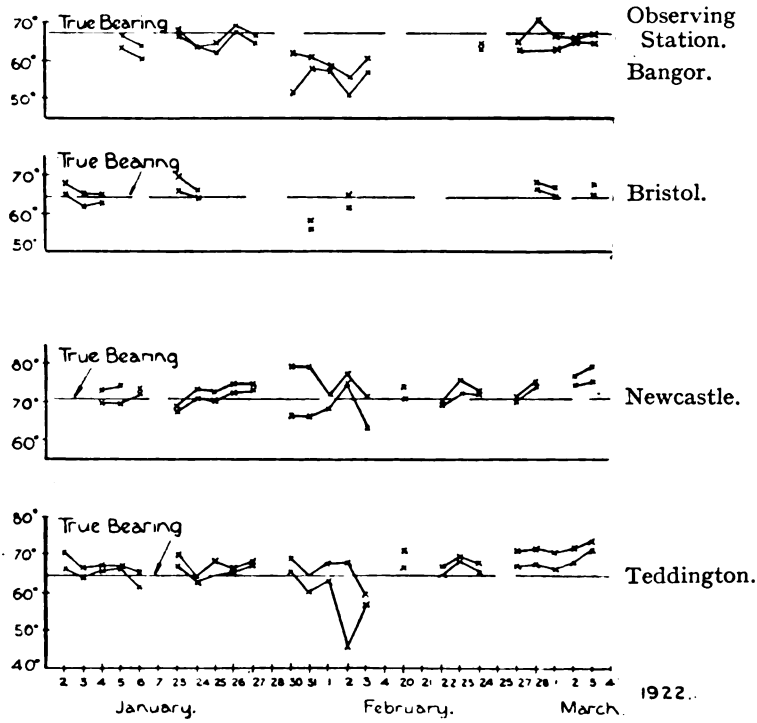

FIG. 28.—GRAPHS OF DAILY EXTREME BEARINGS OF MOSCOW (DAMPED WAVES, $\lambda = 4{\cdot}8$ KM.) AT 20.00 TO 21.00 TRANSMISSIONS.

(*d*) Where the distance of the transmitter is great compared with the distance between the observing stations, as in the case of Karlsborg and Moscow, the variations are very frequently, although not always, similar in direction and extent at the various receiving stations. When it is considered that local conditions around one or more of the latter may often prevent the observation of a bearing at the moment when an excessive variation is present, this similarity is surprisingly marked in Figs. 26–29. With Poldhu, represented in Fig. 30, both bearing and distance vary appreciably for the various stations, and the variations do not display much similarity.

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Deductions (*a*) and (*b*) are in marked contrast to those drawn from the corresponding curves in the day time (*see* (11)) which showed that during an observation period the bearings usually agreed within a fraction of a degree and never differed by more than 2°.

The results plotted for Poldhu in Fig. 30 showed some contrasts with the corresponding day readings in Fig. 13 (making due allowance for the difference of scales of these two figures). It appears also from this diagram that generally when an observed bearing is several degrees different from its normal mean value, it varies appreciably during a period of (in this case) five to ten minutes.

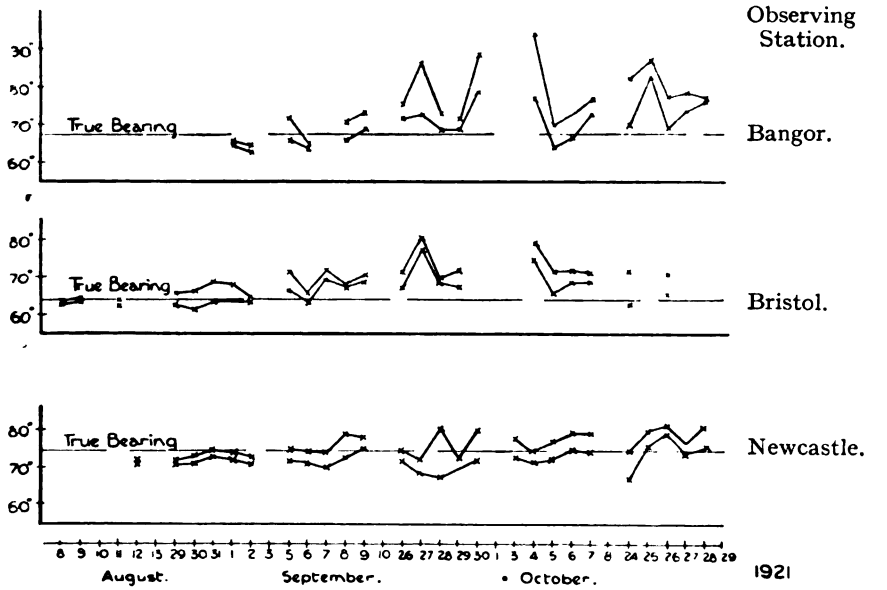

FIG. 29.—GRAPHS OF DAILY EXTREME BEARINGS OF MOSCOW (DAMPED WAVES, $\lambda = 4{\cdot}8$ KM.) AT 18.00 to 20.00 TRANSMISSIONS.

(19) *Graphs of individual bearings*

(*a*) *Occurrences at sunrise and sunset.*—It has already been indicated in sub-section (9) and Table 19 that there are many instances of moderately large fluctuations of observed bearings at periods within $1\frac{1}{2}$ or 2 hours after sunrise, these being attributed to a persistence of night conditions. Also the increase in the variations of Poldhu's bearing at nearly two hours after sunrise was demonstrated in Figs. 7 and 13. Beyond these, the observations recorded so far in the sunrise periods have been somewhat few, due chiefly to the infrequency of transmission of damped wave stations at these times. It is hoped that the extension of the present investigation to undamped wave reception will provide some more evidence upon this point.

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The information available for periods in the neighbourhood of sunset is much greater, and the chief results so obtained may be demonstrated with the aid of Figs. 31–33. In Fig. 31 (*a*) the increase in the extent of the observed variations after sunset is represented for transmission from Clifden to Newcastle, *i.e.*, in an easterly direction. In Fig. 31 (*b*) it is seen that, while the bearings tend to be rather unsteady during the transition period, the more marked variations do not commence until after sunset at Clifden, *i.e.*, over the whole path of transmission. At one to two hours after sunset the bearings are generally erratic.

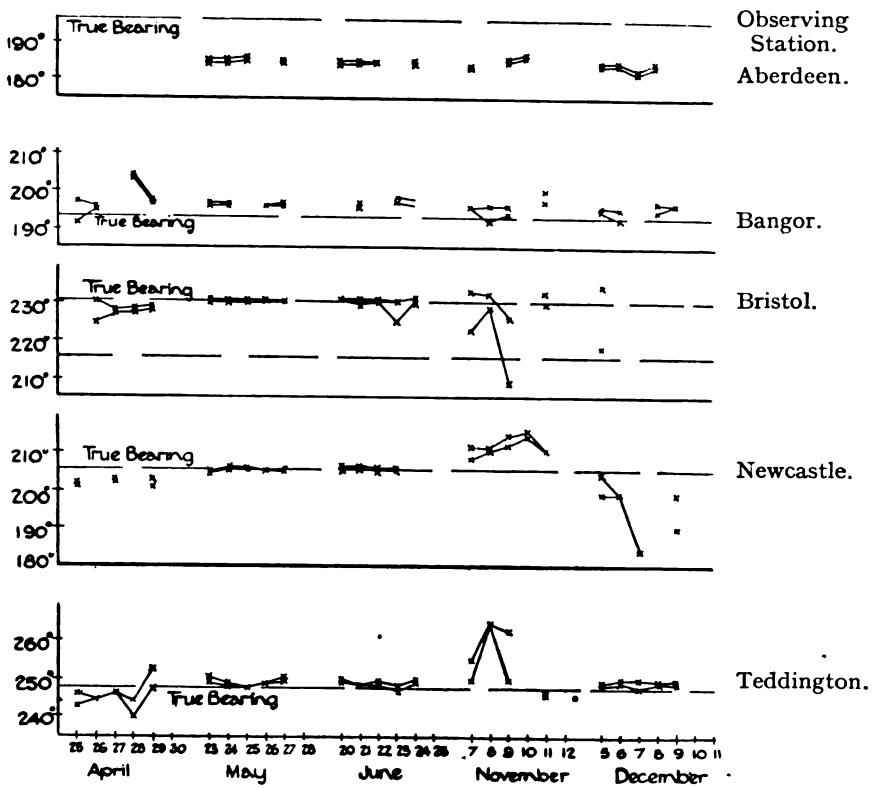

FIG. 30.—GRAPHS OF DAILY EXTREME BEARINGS AT POLDHU (DAMPED WAVES, $\lambda = 2{\cdot}8$ KM.) AT 21.30 TRANSMISSIONS.

In Fig. 32 similar observations on Clifden made at Bangor are shown, not for the same periods, however. While these generally confirm the previous deductions, it is also seen that on some occasions the variations commenced about half an hour before sunset at Bangor and nearly one hour before sunset at Clifden.

Fig. 33 illustrates a week's observations at sunset of the bearings of Moscow at five receiving stations. During this week the fading of signals about one hour before sunset at the receiver was particularly marked, and it is evidenced by the results at all

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stations either by failure to obtain bearings or by the reduced accuracy. The "fading" lasted for a period of from 15 to 30 minutes, and was nearly always accompanied by an appreciable change in the bearing in the same direction. The consistency of this occurrence at all the observing stations is particularly noticeable in this diagram. On an occasion some five months after the

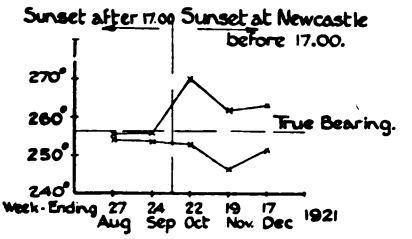

FIG. 31 (*a*).—WEEKLY EXTREME BEARINGS OF CLIFDEN (UNDAMPED WAVES, $\lambda = 5{\cdot}8$ KM., OBSERVED WITHOUT HETERODYNE) AT NEWCASTLE AT 16.30 to 18.00 TRANSMISSIONS.

above observations very similar fading effects were observed on Moscow's signals about 40 minutes before sunset, but in this case they were unaccompanied by any appreciable change in bearings. The observations that have been made at periods coinciding with

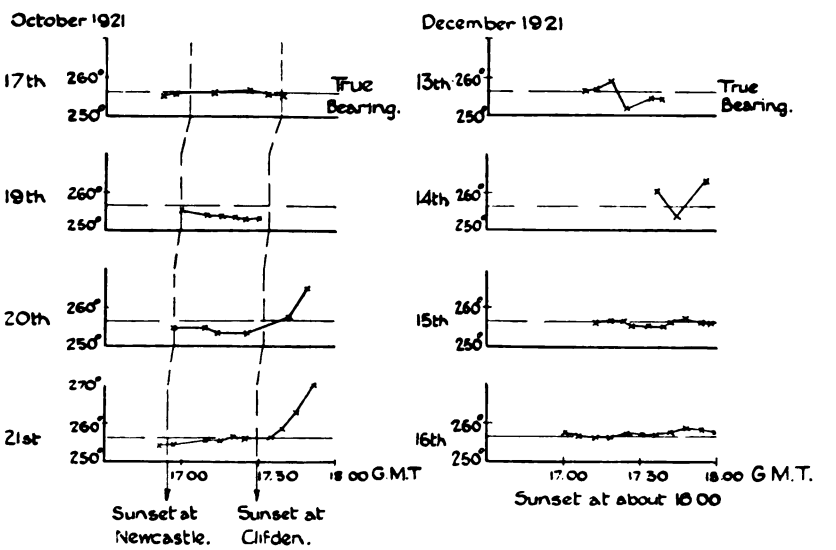

FIG. 31 (*b*).—GRAPHS OF INDIVIDUAL BEARINGS OF CLIFDEN AT NEWCASTLE DURING WEEKS ENDING 22ND OCTOBER AND 17TH DECEMBER, 1921, AS IN FIG. 31 (*a*).

sunset at Moscow have shown only slight fluctuations never exceeding 3° from the mean bearing, an amount which is quite commonly experienced under daylight conditions.

It will be noticed generally from Figs. 31–33 that, after the small erratic fluctuations which occur in the neighbourhood of sunset,

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the first large change in bearing is practically always in the same direction. This change corresponds to an apparent rotation towards the south when the transmission is from the east, and towards the north when the signals arrive from the west. Although subsequent variations tend to be equally distributed about the normal bearing, this fact undoubtedly accounts for the systematic error of the mean night bearings observed on some stations (*see* (13) above).

(*b*) *General night occurrences.*—In Figs. 34–36 the bearings of Karlsborg and Moscow respectively are represented as observed at several stations during the same times over a period of two

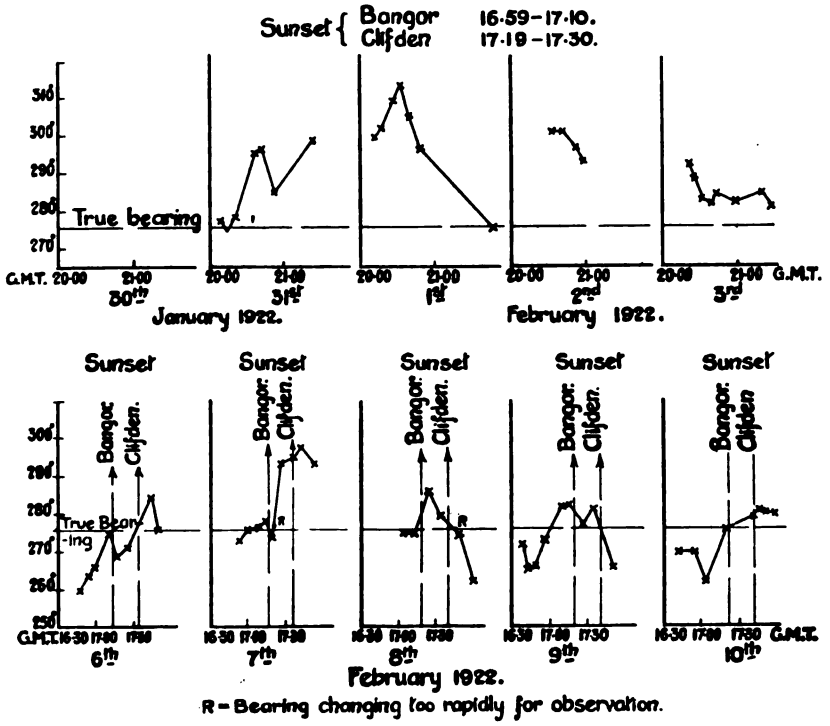

FIG. 32.—GRAPHS OF INDIVIDUAL BEARINGS OF CLIFDEN AT BANGOR.

weeks. It will be seen that the erratic variations observed show only a very general agreement at the different places of observations except where the distance between these is very small compared with the distance of the transmitter (*e.g.* as with Slough and Teddington in Fig. 36). Several cases are shown in which the changes in bearing of the same transmitter are in opposite directions at the different receivers, even though these are approximately on the same great circle. In some cases the bearings of the two transmitters, Karlsborg and Moscow, vary in a similar manner at the same receiver, but in other instances no similarity is shown. Fig. 34 indicates

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several occurrences of a failure to obtain bearings due to either (*a*) interference from atmospherics; (*b*) a change of the received "spark" note on operating the reversing switch of the direction-finding set at the balance position; (*c*) the absence of any change in intensity of the received signal with rotation of the direction-finding coil. These occurrences are, in general, not

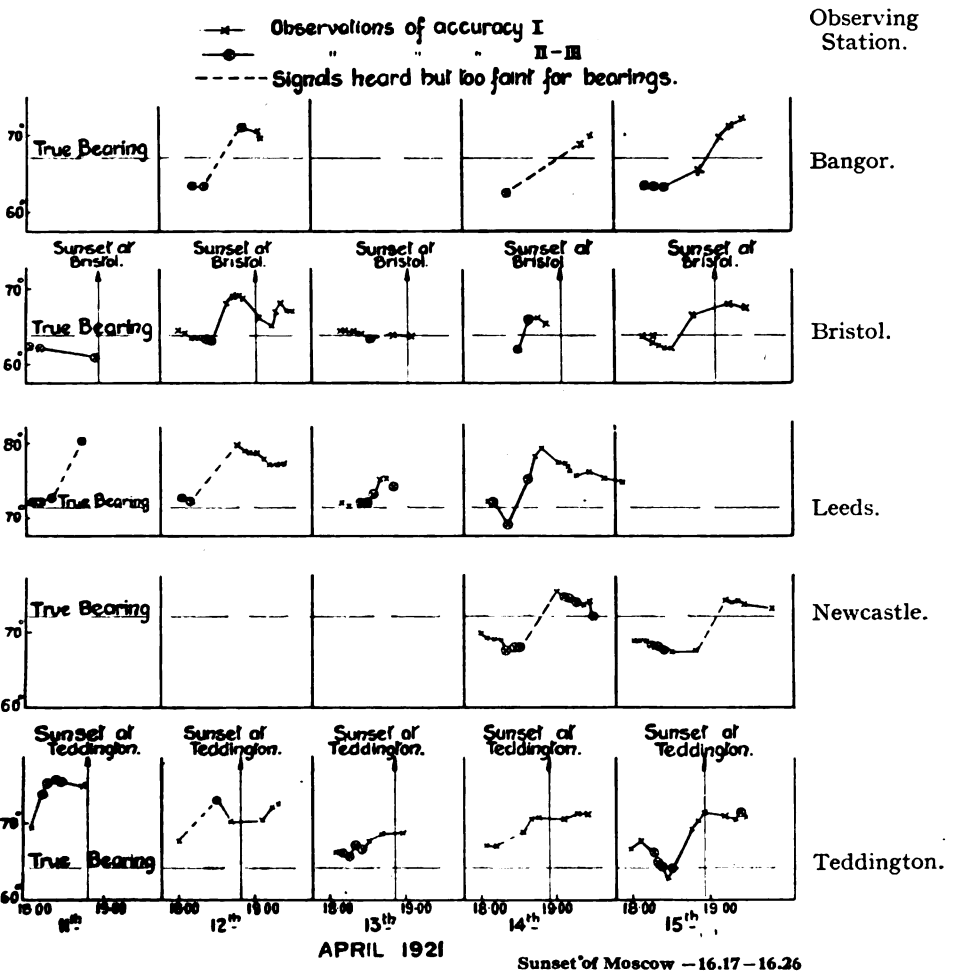

FIG. 33.—GRAPHS OF INDIVIDUAL BEARINGS OF MOSCOW DURING SUNSET AT RECEIVERS.

simultaneous at the different stations. Further discussion on this matter will be given later.

The records of several weeks' observations of the bearings of Karlsborg and Moscow are given in Figs. 37–39, plotted to a larger scale to show more clearly the variations which are almost continuously occurring in the night periods several hours after sunset. These graphs show very clearly that similarity of

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the variations only occurs at two stations situated comparatively close together, such as Slough and Teddington, at a distance of 11 miles. Figs. 37 and 38, for example, show great similarity in the direction and extent of the variations at Slough and Teddington, even when those at another receiving station are in the reverse direction. In Fig. 37 the variations of Moscow's bearing at Slough and Teddington on 24th and 30th of January are very similar, while in marked contrast to those observed at Newcastle simultaneously. It is to be noted that where there is a disagree-

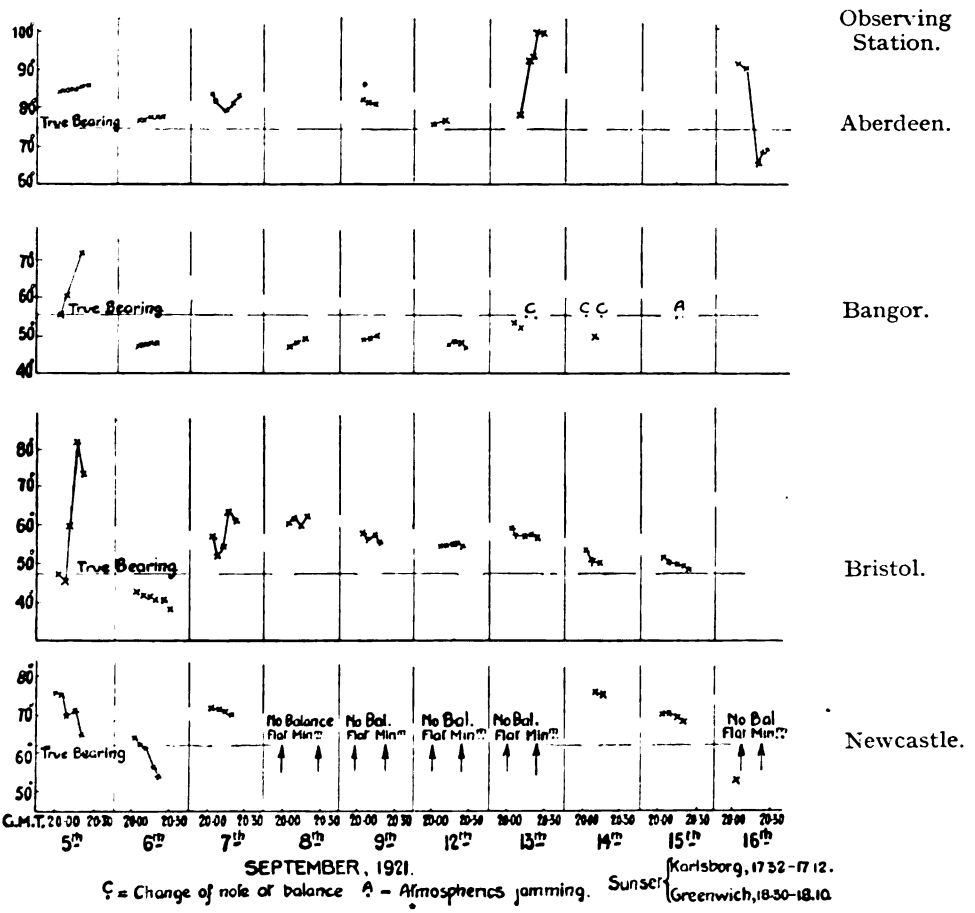

FIG. 34.—GRAPHS OF INDIVIDUAL BEARINGS ON KARLSBORG AT 20.00 TRANSMISSIONS.

ment in the variations experienced at the two neighbouring stations (*i.e.*, Slough and Teddington) the observed bearing is changing very rapidly, sometimes several degrees per minute, in which case very exact synchronisation of observation would be necessary to obtain complete agreement. The enormous difference in the amplitude of variations observed by day and night is shown by the comparative readings given in Fig. 38 to the same scale.

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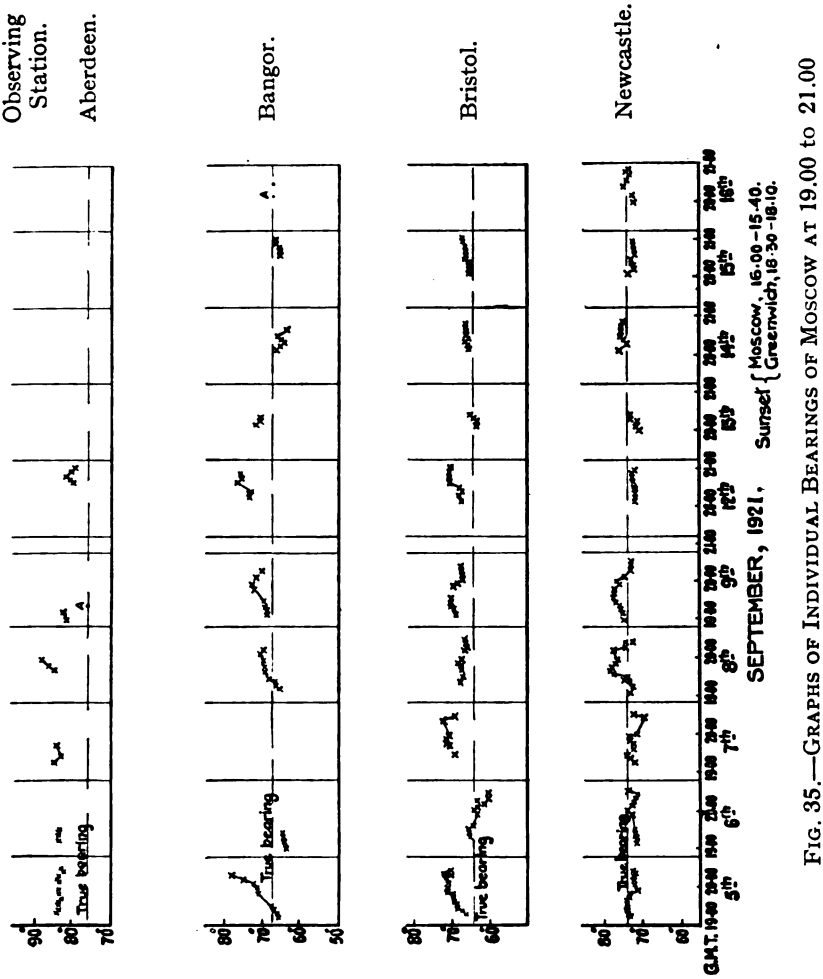

FIG. 35.—GRAPHS OF INDIVIDUAL BEARINGS OF MOSCOW AT 19.00 TO 21.00 TRANSMISSIONS.

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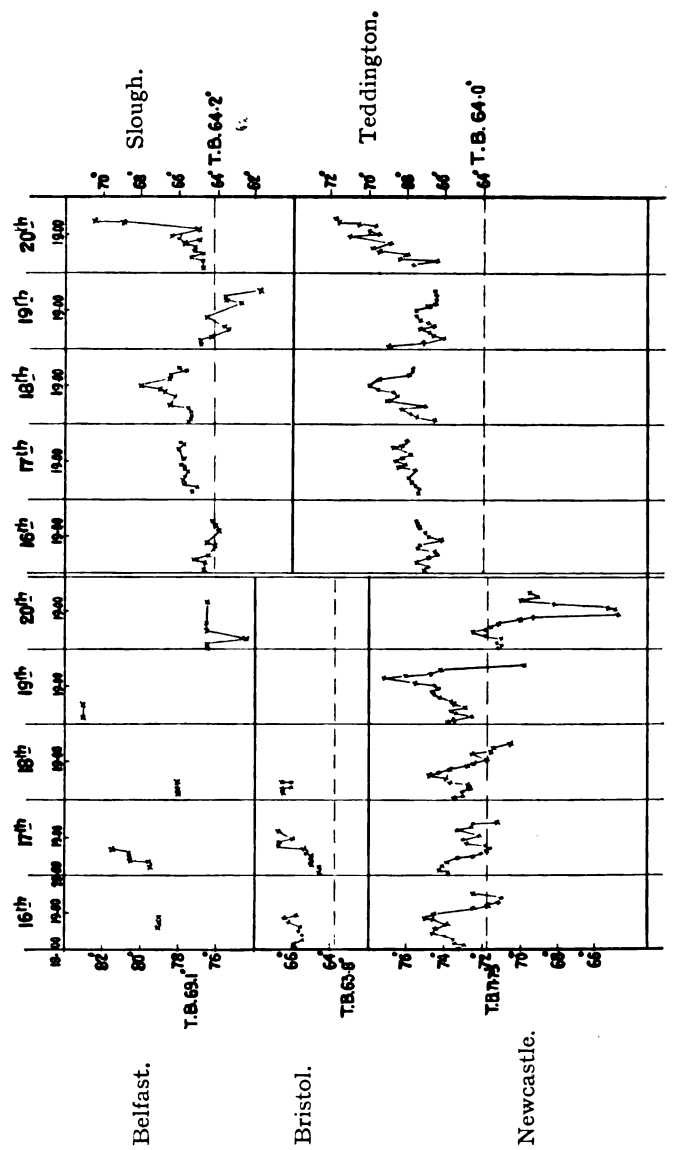

FIG. 36.—OBSERVATIONS ON MOSCOW FOR WEEK ENDING 21.1.22.

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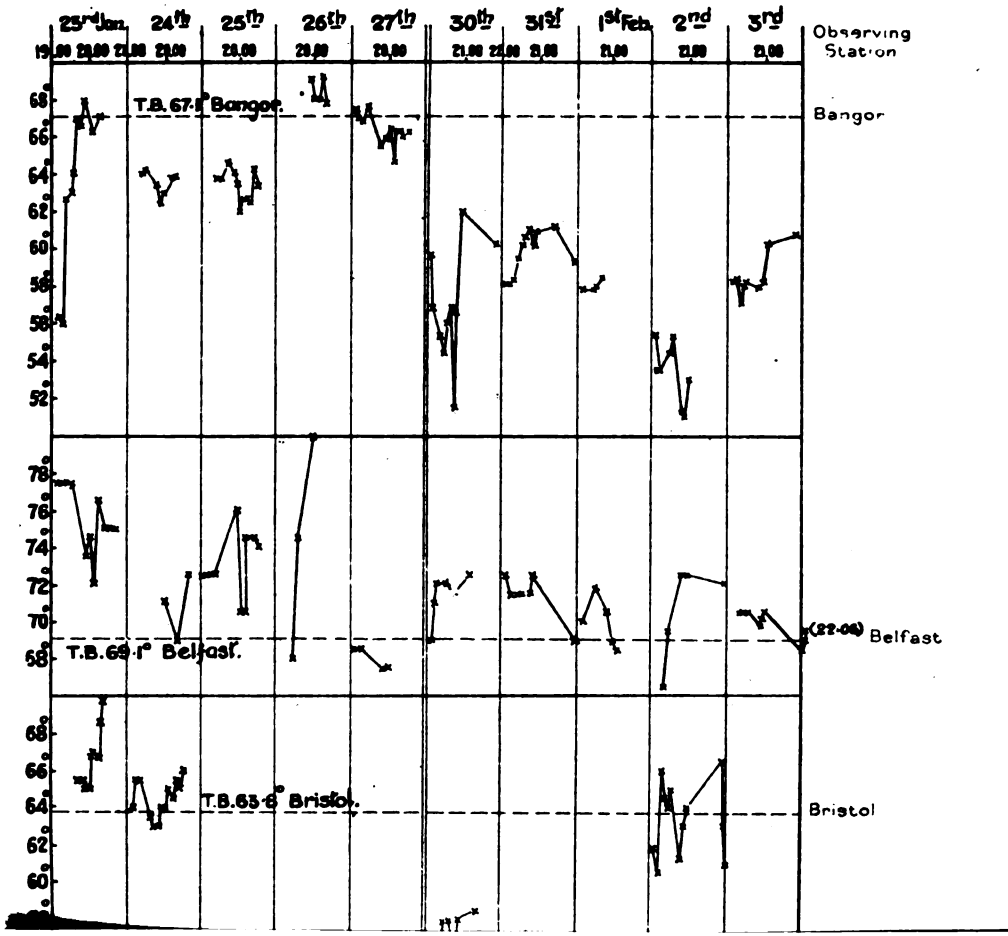

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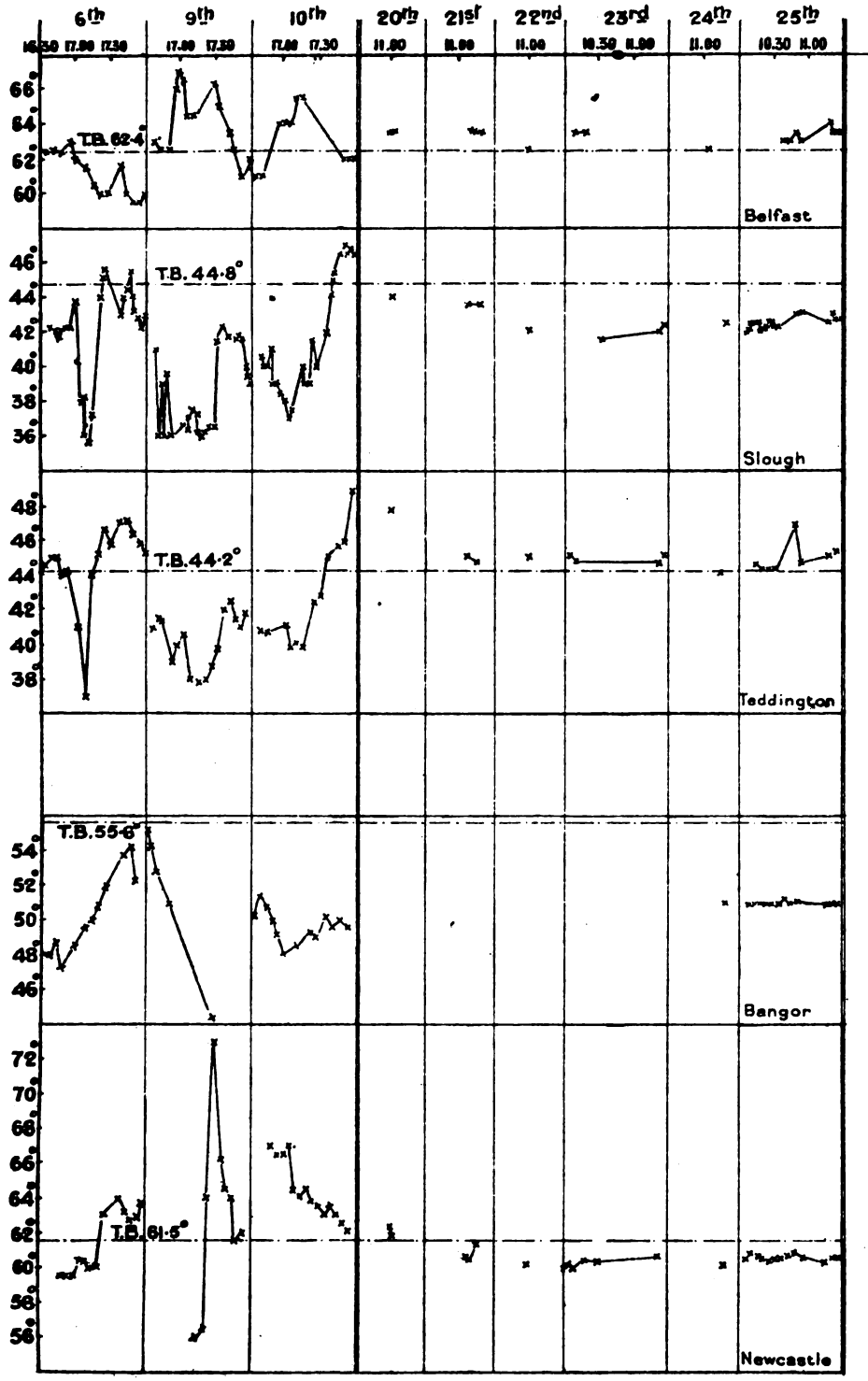

OBSERVATIONS ON KARLSBORG (DAMPED WAVES λ - 4·2 KM.)
FOR TWO WEEKS ENDING $\left\{\frac{11\cdot2\cdot22}{25\cdot2\cdot22}\right.$

FIG. 38.

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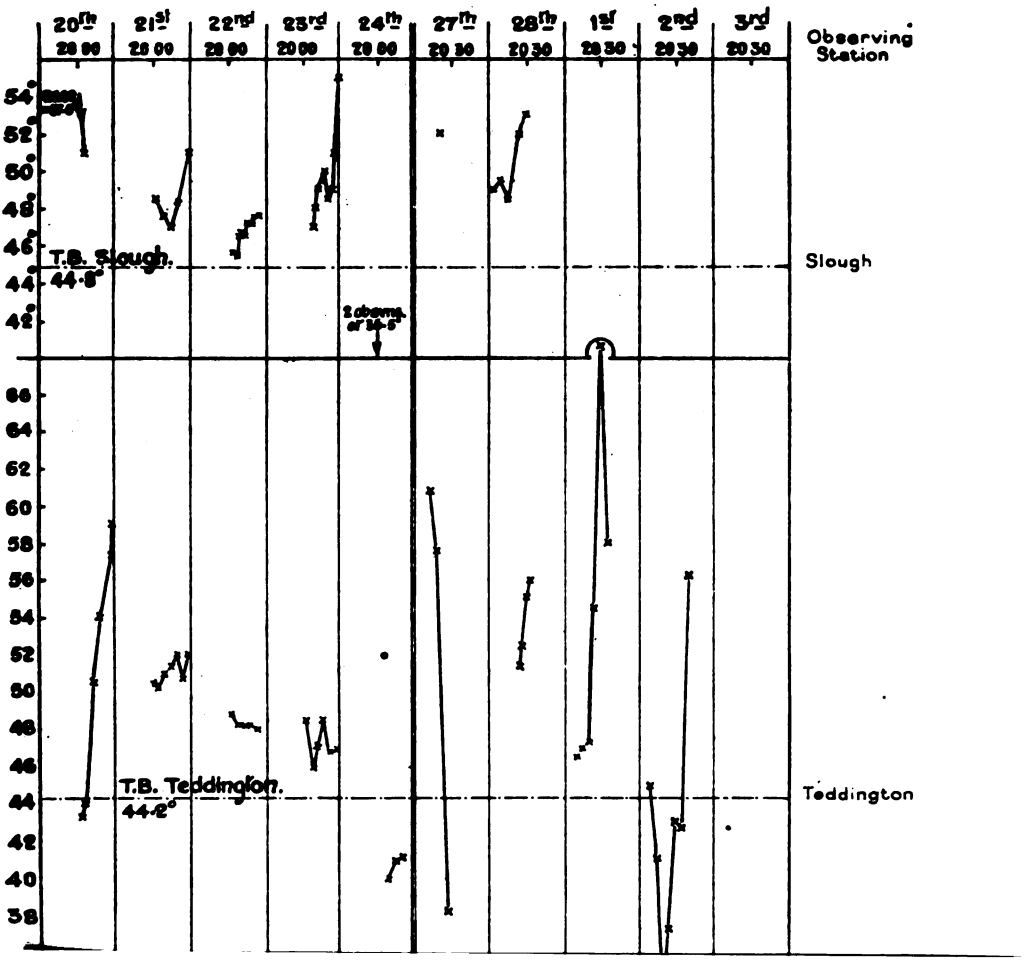

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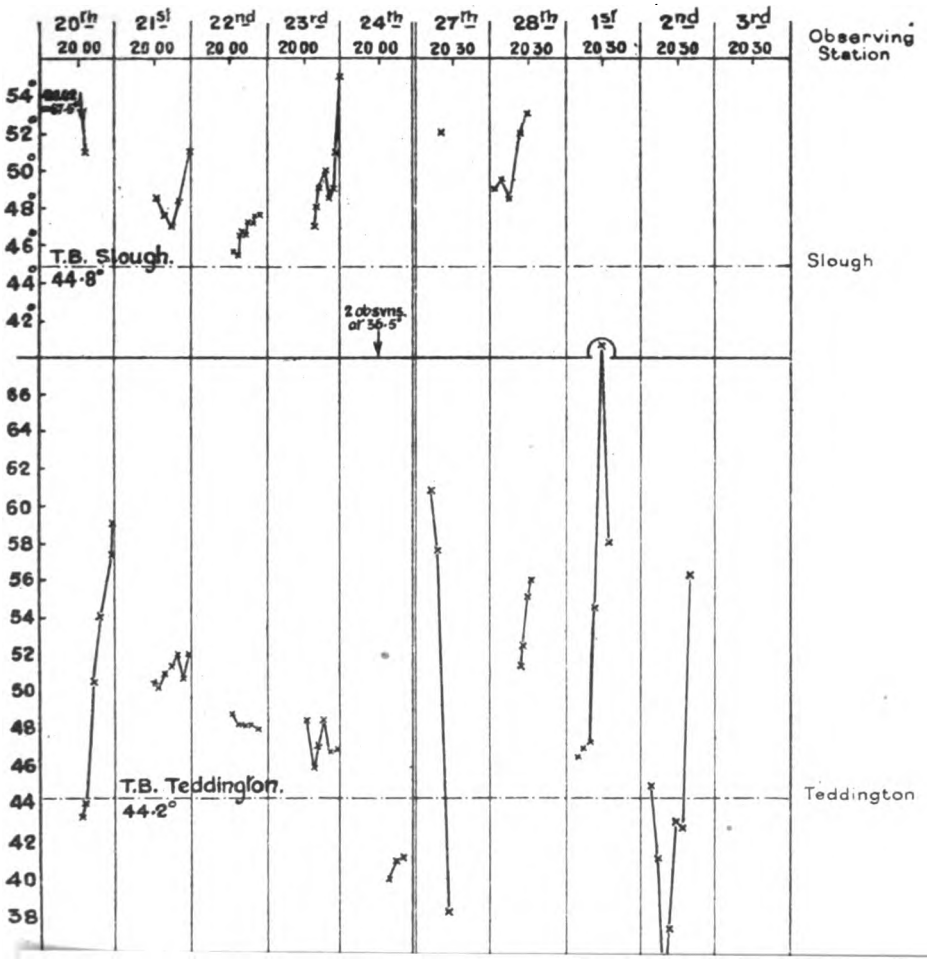

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(20) *Continuous observations over 24-hour periods*

During the present investigation little opportunity has been obtained for making continuous observations over a period of 24 hours, due not only to the need for more than one observer at each station for such a test, but also to the absence of any damped wave station giving sufficiently continuous transmission. Advantage was, however, taken of some special transmissions from Horsea during September, 1921, to make a few continuous observations, and some of the results obtained are plotted in Fig. 40. This diagram shows very clearly the following points, all of which confirm previous deductions :—

(*a*) While during the daytime the observed bearings never vary more than 1° from the mean, the variations at "night" range to some 6° on either side of the mean.

(*b*) The variations usually commence within one hour before sunset, and after increasing in range, continue all through the night until one or two hours after sunrise.

(*c*) On some occasions a progressive change in bearing is observed, while on others the variation rapidly passes from one side to the other of the true bearing.

(*d*) The variations are as likely to occur on one wave-length as on another over the range used.

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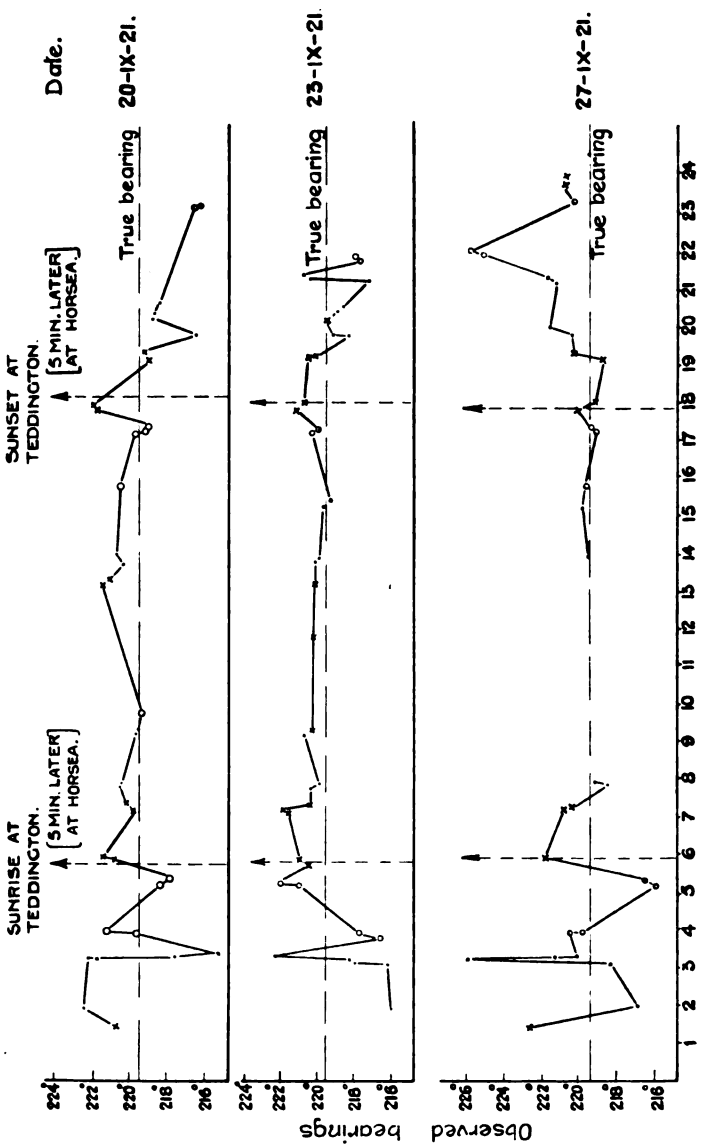

FIG. 40.—OBSERVATIONS OF BEARING OF HORSEA AT TEDDINGTON OVER 24-HOUR PERIODS.

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(21) *Extent of variations at short distances*

It has already been noted that the greatest night variations are fairly well distributed over all ranges of transmission of from 150 to 1,500 miles (see 15 above). The following Table No. 23 shows that the variations are somewhat less though still quite appreciable at shorter distances down to 41 miles.

TABLE NO. 23.—VARIATIONS AT DISTANCES LESS THAN 100 MILES

Observing station.	Transmitting station.	Distance.	Total variation.
		(miles)	(degrees)
Aberdeen	Aberdeen	4·6	2·3
Bristol	Horsea	78	13·5
,, ...	Chelmsford ..	133	17·0
Newcastle	Cleethorpes ..	118	12·0
Peterborough ..	,, ...	68	2·5
Teddington ..	Chelmsford ..	41	19·3
,, ...	Horsea	52	8·3
,, ...	Whitehall	10	3·4

In the only two instances of transmission over distances of less than 40 miles, no appreciable difference in the variations by day and night has been observed, and all bearings obtained at these short distances have shown a maximum variation of only 3·4°.

SECTION V.—CONCLUDING DISCUSSION ON THE INVESTIGATION

ALTHOUGH during this investigation the Robinson system has been employed throughout, a series of special experiments in which Bellini-Tosi and single-frame coil sets were used in addition, showed that all three systems are equally subject to these variations to exactly the same extent, neglecting any differences in instrumental errors [3].

The results collected and discussed in the previous sections show quite well that these variations are so erratic in their frequency and magnitude that it is only by regular observation of a large number of bearings that any reliable and tangible deductions may be drawn. This has been brought out during the course of the experiments, for many conclusions arrived at hastily in the early stages of the investigation have been modified and sometimes completely reversed by further observations.

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(22).—*Percentage of errors*

In the present instance it is considered that the results are so numerous and so consistent as to permit of the few conclusions already drawn. Out of the 41,000 readings here dealt with, the greatest variation recorded is 66°, for the observations of Karlsborg at Aberdeen. This, however, corresponds to an actual error from the mean of only 39°.

The following tables Nos. 24-27 give the numbers and percentages of the results which differ from the mean by certain fixed amounts up to 20°, as observed at the four stations where the greatest number of readings were made.

Viewed in this manner it is seen that during the day there is an appreciable number of readings which are more than 2° in error. The number of readings which correspond to an error of more than 5° is very small, and these can almost entirely be accounted for by their being taken near sunrise. At night, however, a comparatively large proportion of the readings are between 5° and 10° in error; larger errors than this are infrequent, while a bearing corresponding to an error of more than 20° is so rare an occurrence that the possibility is quite negligible for any practical uses of direction-finding.

This point can be realised from the curves previously given, which show that the more serious departures of the observed bearing are of only short duration. The rate of change of the bearing at night varies over a wide range, from one or two degrees in ten minutes up to a maximum observed alteration of 37.5° in ten minutes.

This maximum alteration was in the observation of Karlsborg at Bristol on 5th September, 1921. During the same period at Bangor an alteration of bearing of 15° was experienced, whereas at Aberdeen and Newcastle the observed bearing was steady within three or four degrees. On many other occasions also the bearings were varying so rapidly that as mentioned below, an accurate observation was impossible.

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TABLE NO. 24.—PERCENTAGE DIFFERENCES FROM ANNUAL MEAN AT BANGOR

Transmitting Station.	Total No. of observations.		More than ± 2·0°.				More than ± 5·0°.				More than ± 10·0°.				More than ± 20·0°.			
			Day.		Night.		Day.		Night.		Day.		Night.		Day.		Night.	
	Day.	Night.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.
Aberdeen	34	18	10	29·4	—	—	7	20·6	—	—	1	3·0	—	—	—	—	—	—
Budapest	33	114	2	6·0	49	43·0	—	—	11	9·6	—	—	3	2·6	—	—	—	—
Carnarvon	119	176	42	35·3	21	11·9	17	14·3	33	18·9	—	—	—	—	—	—	—	—
Chelmsford	43	36	1	2·3	14	3·9	—	—	7	1·9	—	—	1	2·8	—	—	2	5·6
Cleethorpes	17	86	3	17·6	39	47·3	5	29·4	7	8·2	—	—	4	4·6	—	—	—	—
Clifden	180	141	13	7·2	22	15·6	—	—	25	17·7	—	—	33	23·5	—	—	14	9·9
Coltano	77	13	—	—	2	15·4	—	—	3	23·1	—	—	—	—	—	—	—	—
Horsea	78	162	9	11·5	39	24·1	—	—	31	19·1	—	—	10	6·1	—	—	—	—
Karlsborg, Spk. 2·5 ...	17	271	—	—	121	44·6	—	—	37	13·6	—	—	11	4·1	—	—	7	2·5
,, ,, 4·2 ...	79	63	6	7·6	20	31·7	—	—	1	1·6	—	—	2	3·2	—	—	—	—
Konigswusterhausen... ...	92	—	13	14·1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Moscow	5	591	—	—	276	46·7	—	—	102	17·2	—	—	32	5·4	—	—	2	0·3
Nantes, 2·4	13	22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 4·2	32	19	1	3·1	2	10·5	—	—	—	—	—	—	—	—	—	—	—	—
Nauen, Spk. 3·2	121	—	41	33·9	—	—	7	5·8	—	—	—	—	—	—	—	—	—	—
,, C.W. 4·9	21	55	5	23·8	19	34·5	—	—	14	26·3	—	—	1	1·8	—	—	—	—
Nicolaieff	5	52	—	—	11	21·1	—	—	1	1·9	—	—	—	—	—	—	—	—
Paris, Spk. 2·6 08.15 ...	164	—	28	17·1	—	—	2	1·2	—	—	—	—	—	—	—	—	—	—
,, 2·6 09.20 ...	506	—	30	5·1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 2·6 11.30 ...	254	—	1	0·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 2·6 19.20 ...	—	211	—	—	72	34·1	—	—	26	12·3	—	—	6	2·8	—	—	—	—
,, 3·2	402	—	21	5·2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Poldhu 09.30 and 21.30 ...	172	110	—	—	20	18·2	—	—	9	8·2	—	—	3	2·7	—	—	—	—
,, ...	18	32	—	—	18	56·2	—	—	3	9·4	—	—	—	—	—	—	—	—
Total	2,482	2,172	226	9·1	745	34·3	38	1·5	310	14·3	1	0·04	106	4·9	—	—	25	1·2

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TABLE NO. 25.—PERCENTAGE DIFFERENCES FROM ANNUAL MEAN AT BRISTOL

Transmitting Station.	Total No. of observations.		More than ± 2·0°.				More than ± 5·0°.				More than ± 10·0°.				More than ± 20·0°.			
			Day.		Night.		Day.		Night.		Day.		Night.		Day.		Night.	
	Day.	Night.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.
Aranjuez	112	242	2	1·8	12	4·9	—	—	—	—	—	—	—	—	—	—	—	—
Budapest	49	316	3	6·1	233	73·6	—	—	38	12·0	—	—	6	1·9	—	—	—	—
Chelmsford	244	169	4	1·6	11	6·5	—	—	11	6·5	—	—	1	0·6	—	—	—	—
Cleethorpes, Spk. 3·0 ...	21	23	—	—	8	34·8	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, ...	—	111	—	—	13	11·7	—	—	3	2·7	—	—	—	—	—	—	—	—
,, C.W. 4·6 ...	13	12	3	23·1	3	25·0	2	15·4	—	—	—	—	—	—	—	—	—	—
Clifden	38	68	—	—	10	14·7	—	—	2	2·9	—	—	—	—	—	—	—	—
Coltano	42	40	—	—	2	5·0	—	—	—	—	—	—	—	—	—	—	—	—
Horsea	189	428	11	5·8	95	22·2	—	—	20	4·7	—	—	—	—	—	—	—	—
Karlsborg, Spk. 2·5 20·00 ...	—	340	—	—	136	40·0	—	—	50	14·7	—	—	16	4·7	—	—	6	1·7
,, 4·0	19	25	2	10·5	7	28·0	—	—	—	—	—	—	—	—	—	—	—	—
Moscow	3	1,245	—	—	166	13·3	—	—	76	6·1	—	—	2	0·1	—	—	—	—
Nantes, Spk. 2·4	—	14	—	—	1	7·1	—	—	—	—	—	—	—	—	—	—	—	—
,, 4·2	28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 4·2	—	14	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nauen, Spk. 3·9	155	—	2	1·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nicolaieff	7	8	1	14·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Paris, Spk. 2·6	—	28	—	—	2	7·1	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 08.15 ...	116	—	1	0·8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 09.20-11.00	566	—	10	1·8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 11.30-11.50	289	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 19.20 ...	—	147	—	—	21	14·3	—	—	3	2·0	—	—	—	—	—	—	—	—
,, ,, 2·6 21.10 ...	—	100	—	—	30	30·0	—	—	12	12·0	—	—	1	1·0	—	—	—	—
,, ,, 3·2 11.00-11.30	304	—	1	0·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 3·2 12.00-12.30	76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Poldhu, Spk. 2·8	79	398	3	3·8	36	9·5	—	—	66	16·6	—	—	53	13·3	—	—	8	2·0
,, ,, 09.30 and 21.30	145	156	2	1·4	47	30·0	—	—	7	4·8	—	—	10	6·8	—	—	—	—
Sofia	—	24	—	—	8	33·3	—	—	3	12·5	—	—	—	—	—	—	—	—
Total	2,495	3,908	45	1·8	841	21·5	2	0·08	291	7·4	Nil.	—	89	2·3	Nil.	—	14	0·4

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TABLE No. 26.—PERCENTAGE DIFFERENCES FROM ANNUAL MEAN AT NEWCASTLE

Transmitting Station.	Total No. of observations.		More than ± 2·0°.				More than ± 5·0°.				More than ± 10·0°.				More than ± 20·0°.			
			Day.		Night.		Day.		Night.		Day.		Night.		Day.		Night.	
	Day.	Night.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.
Aberdeen	100	37	36	36·0	21	56·7	2	2·0	4	10·8	—	—	1	2·7	—	—	—	—
Aranjuez	65	102	—	—	8	7·8	—	—	—	—	—	—	—	—	—	—	—	—
Budapest	45	527	—	—	118	22·4	—	—	12	2·3	—	—	6	1·1	—	—	—	—
Chelmsford	126	256	2	1·6	4	1·6	—	—	—	—	—	—	—	—	—	—	—	—
Cleethorpes, Spk. 3·2 ...	—	87	—	—	3	3·4	—	—	—	—	—	—	—	—	—	—	—	—
,, C.W. 4·5 ...	72	134	20	27·8	34	33·0	1	1·39	4	3·0	—	—	—	—	—	—	—	—
Clifden, Spk. 5·8 ...	64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, C.W. 5·8	95	182	10	10·5	55	30·0	2	2·1	22	12·1	—	—	5	2·7	—	—	—	—
Coltano	141	43	—	—	5	11·6	—	—	2	4·7	—	—	—	—	—	—	—	—
Horsea	204	392	20	9·8	59	15·0	—	—	6	1·5	—	—	—	—	—	—	—	—
Karlsborg, Spk. 2·5 ...	33	441	2	6·1	323	74·0	—	—	112	25·4	—	—	41	9·3	—	—	4	0·9
,, ,, 4·2... ...	207	128	12	5·7	64	50·0	1	0·48	26	20·3	—	—	3	2·3	—	—	—	—
,, C.W. 4·5... ...	27	—	1	3·7	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Moscow	18	1,838	—	—	536	29·2	—	—	124	6·7	—	—	6	0·0	—	—	1	0·0
Nauen, Spk. 3·2	269	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, C.W. 4·9	50	27	10	20·0	19	70·0	3	6·0	9	33·3	—	—	—	—	—	—	—	—
Nicolaieff	160	106	5	3·1	47	44·2	—	—	5	4·7	—	—	—	—	—	—	—	—
Paris, Spk. 2·6 08.15 ...	202	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 09.20 ...	1,138	—	10	0·99	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 11.30 ...	605	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, ,, 2·6 19.20 ...	—	448	—	—	36	8·0	—	—	—	—	—	—	—	—	—	—	—	—
,, 3·2	537	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Poldhu, Spk. 09.30 and 21.30	365	172	10	2·7	94	55·0	—	—	45	26·2	—	—	11	6·4	—	—	1	0·58
,, ,, ...	14	17	—	—	14	82·4	—	—	5	29·4	—	—	1	5·9	—	—	1	5·9
Sofia	7	166	—	—	62	37·3	—	—	2	1·2	—	—	—	—	—	—	—	—
Warsaw	60	23	1	1·7	5	21·7	—	—	—	—	—	—	—	—	—	—	—	—
Total	4,604	5,126	139	3·0	1,507	29·4	9	0·2	378	7·4	Nil.	—	74	1·44	Nil.	—	7	1·14

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TABLE NO. 27.—PERCENTAGE DIFFERENCES FROM ANNUAL MEAN AT TEDDINGTON

Transmitting Station.	Total No. of observations.		More than ± 2·0°.				More than ± 5·0°.				More than ± 10·0°.				More than ± 20·0°.			
			Day.		Night.		Day.		Night.		Day.		Night.		Day.		Night.	
	Day.	Night.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.
Budapest	144	307	8	5·5	92	30·0	2	1·4	26	8·5	2	1·4	5	1·6	—	—	—	—
Chelmsford	667	682	42	6·3	129	19·0	1	0·15	18	2·64	—	—	1	0·15	—	—	—	—
Cleethorpes, Spk. 3·0 ...	—	84	—	—	6	7·1	—	—	2	2·4	—	—	—	—	—	—	—	—
Clifden, Spk. 5·7	47	—	2	4·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Coltano	194	51	—	—	24	47·0	—	—	5	9·8	—	—	3	5·9	—	—	—	—
Horsea	125	328	—	—	25	7·6	—	—	1	0·3	—	—	—	—	—	—	—	—
Karlsborg, Spk. 2·5	—	320	—	—	221	69·0	—	—	79	24·7	—	—	20	6·2	—	—	1	0·3
,, ,, 4·2	60	112	8	13·3	73	65·0	—	—	22	19·6	—	—	5	4·5	—	—	—	—
Moscow	37	1,255	1	2·7	395	31·2	—	—	106	8·35	—	—	8	0·6	—	—	3	0·2
Nantes, Spk. 2·5	10	39	—	—	4	10·3	—	—	1	2·56	—	—	—	—	—	—	—	—
,, 4·2	38	46	3	7·9	27	59·0	—	—	10	21·8	—	—	—	—	—	—	—	—
Nauen, Spk. 3·2	186	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nicolaieff	62	45	1	1·6	13	29·0	—	—	4	8·9	—	—	—	—	—	—	—	—
Paris, Spk. 2·6 08.15 ...	312	—	1	0·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 2·6 09.20 ...	599	—	2	0·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 2·6 11.30 ...	272	—	2	0·7	—	—	—	—	—	—	—	—	—	—	—	—	—	—
,, 2·6 19.20 ...	—	242	—	—	8	3·3	—	—	—	—	—	—	—	—	—	—	—	—
,, 3·2	357	—	5	1·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Le Vallois	305	203	33	11·0	45	22·0	—	—	10	4·93	—	—	2	0·99	—	—	—	—
Poldhu, 09.30 and 21.30 ...	295	190	1	0·3	127	67·0	—	—	51	26·8	—	—	17	8·9	—	—	—	—
,, ,, ,, ...	—	30	—	—	21	70·0	—	—	3	10·0	—	—	2	6·7	—	—	—	—
Sofia	—	178	—	—	56	31·5	—	—	4	2·25	—	—	1	0·6	—	—	—	—
Warsaw	21	14	1	4·7	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Whitehall	48	46	—	—	1	2·0	—	—	—	—	—	—	—	—	—	—	—	—
Total	3,779	4,172	110	2·9	1,267	30·5	3	0·08	342	8·2	2	0·05	64	1·5	—	—	4	0·09

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(23).—*Failure to obtain bearings*

In general working the chief causes of being unable to obtain bearing observations were the weakness of received signals and interference. Owing to the large difference in intensity from day to night of the signals from the more distant stations such as Budapest, Moscow and Nicolaieff, there are many cases of regular observations being made at night, whereas observations on the same stations by day were few and at comparatively rare intervals. In other cases also the strength of received signals was quite adequate for accurate observation but for the presence of interference from other signals on the same or neighbouring wave-lengths. Accurate observations under these conditions are very difficult, due not merely to the presence of the interfering signals, but rather to their change in intensity as the commutating switch is operated. For in the general case in which the interference is from a different direction from that of the required signal, the intensities corresponding to the two positions of the switch will be very different. The effect of this interference varies greatly with the position of the receiver relative to the interfering transmitting station. For example, the signals from Paris (spark), received in the south of England were usually so strong as entirely to prevent other observations on neighbouring wave-lengths, whereas this difficulty was absent in the North of England and Scotland.

The interference was not confined to spark stations, however; for example, the continuous wave transmissions from Nauen on 4·7 km. made it somewhat difficult to make accurate observations on Moscow's 4·8 damped waves. Much trouble has, in fact, been caused during the investigation from this cause, which is really attributable to the impurity of the continuous waves emitted. The extent of this impurity or modulation of the waves is evidenced by the case of the reception of C.W. signals from Clifden and Nauen on this small coil direction-finder. Although these two stations are distant from Newcastle by 355 and 612 miles respectively, adequate signals for the accurate observation of bearings to $\pm 1°$ were possible without the use of heterodyne reception.

Quite apart from signal interference much trouble has also been experienced at times, and particularly during the summer evening periods, due to atmospheric disturbances. On certain occasions these have been so strong as to make observations on any but the strongest signals very difficult indeed. For this reason it is not easy to obtain any evidence connecting strength of atmospherics with variations, but in any case no necessary relation between these has so far been observed.

In the evening periods it has occasionally been difficult or even impossible to obtain bearings due to various causes including those just mentioned. A summary of the records of these instances as noted by the observers at six receiving stations is given in Table No. 28 below.

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TABLE No. 28.—SUMMARY OF CASES IN WHICH NO BEARING COULD BE OBSERVED IN THE EVENING PERIODS

Observing Station.	Total No. of readings obtained (evening only).	Signals heard, but bearings impossible, due to										Total.	
		Weak signals.		Interference.		Change of note on reversal.		Bearing changing too rapidly.		Minimum too flat.			
		No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.	No. obs.	Per cent.
Aberdeen	1,186	37	3·1	41	3·5	2	0·2	—	—	27	2·3	107	9·0
Bangor	2,184	76	3·5	35	1·6	128	5·8	35	1·6	—	—	274	12·5
Bristol	3,958	22	0·6	16	0·4	—	—	1	—	—	—	39	1·0
Newcastle	5,169	76	1·5	76	1·5	20	0·4	1	—	34	0·7	213	4·1
Peterborough	1,640	37	2·3	32	1·9	3	0·2	2	0·1	6	0·4	80	4·9
Teddington	4,192	60	1·4	60	1·4	5	0·1	—	—	4	0·2	129	3·1

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It will be seen from this table that the most frequently recorded instances of failure to obtain a bearing were at Aberdeen and Bangor, but whereas at the former station weakness of signals and interference formed the chief difficulties, at the latter, the change in character of the (spark) note received was most noticeable. The effect was a change in the character of the musical note heard in the telephones for the two positions of the reversing switch, and makes an accurate comparison extremely difficult. Although the phenomenon has never been noticed in the daytime, it has occurred on several transmitters, most frequently on Poldhu and Karlsborg, stations which gave spark notes of widely different frequencies. The nature of this effect seems to indicate the arrival of two waves at the receiver slightly out of phase with each other.

Since the Robinson system operates by effectively swinging a single equivalent coil through an angle of the order of 30° for the sets used in this investigation, the sharpness of the minimum of signal strength is not ordinarily observed in the normal taking of bearings. In some cases, however, as noted in the table above, the minima become very flat, so that there is very little change in signal intensity as the coil system is rotated through 360°. This effect may again be attributable to the arrival of two waves out of phase, and producing a non-linear field at the receiver. The proportion of instances in which this has been observed to occur is, however, very small, being always less than 2 per cent. in this investigation.

(24).—*Conclusions and acknowledgments*

No attempt is here made to co-ordinate the observations with theoretical deductions. Many of the conclusions arrived at are based on somewhat scanty evidence even considering the large scale upon which this investigation is conducted. From the termination of the period at present under review (viz., 4th March, 1922), the work was continued for a second year, on practically the same scale and with all the receiving sets equipped for observation on continuous waves. It remains, therefore, to be seen if these additional data will confirm the present results and what new deductions may be obtained.

The author wishes to acknowledge a great deal of very helpful advice and criticism from the members of the Committee of the Radio Research Board, under whose direction the investigation was carried out.

Acknowledgment is also due to the various observers, detailed in page x, for the ready and efficient manner in which the observations were carried out to the author's instructions, and for accurately recording the various effects observed throughout the investigation.

Finally, the author is greatly indebted to Mr. S. R. Chapman, B.Sc., for his willing and untiring assistance in the calculation and checking of true bearings, and in the reduction of the large mass of observations received.

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VARIATIONS OF APPARENT BEARINGS OF RADIO TRANSMITTING STATIONS

PART II—OBSERVATIONS ON FIXED STATIONS MARCH, 1922--APRIL, 1924

By R. L. Smith-Rose, Ph.D., M.Sc., D.I.C., A.R.C.Sc., A.M.I.E.E.
(of the National Physical Laboratory)

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INTRODUCTORY NOTE

A BRIEF outline of the scheme of the investigation of the variations of bearings of radio transmitting stations was given in the Introductory Note to Part I of this Report.* Part II here presented deals with the progress of the investigation from March, 1922, to June, 1923, when observations on the longer waves of 2,000 to 9,000 metres were discontinued at all the University and Service stations forming the original organisation. In July, 1923, the opportunity occurred for carrying out some further observations at a station in higher latitudes than in England, viz., at Lerwick, Shetland Islands. These observations were continued until April, 1924, and the discussion of the results obtained is included in this Part of the Report.

The discussion of the remaining observations carried out on the shorter wave-lengths down to those of 450 metres from 1922–24 will follow in the publication of Part III of the Report.

In referring to the results contained in the present publication it is desirable again to emphasise the difference in effects which have been observed in working overland and oversea. On the longer waves the situation of the transmitting and observing stations was such that all the paths of transmission less than 200 miles in length were entirely overland, and this fact undoubtedly accounts for the abnormally large variations which have been recorded at night for ranges of from 100 miles down to 30 miles. For distances of less than 30 miles, the majority of the direction-finder readings are found to be accurate to within 2° (see Table 17 and p. 78). When the path between the transmitting and observing stations is entirely oversea, and free from any land or coastline effects, the errors in observed bearings are found to lie within the above 2° limits for all ranges up to nearly 100 miles. This accuracy is generally sufficient for most navigational purposes; also, for oversea working a 100 miles range is adequate for the ordinary application of radio direction-finding to marine navigation.

F. E. SMITH,
Chairman of the Committee on Directional Wireless.

August, 1925.

* Issued as Special Report No. 2 of the Radio Research Board.

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Radio Direction-Finding Sets in use from 6.3.22 to 19.4.24

No.	Situation.	Responsible Authority.	Supervisor of Observations.	Observers.	Duration of Observations.
1	Aberdeen ..	The University	Prof. H. M. Macdonald, F.R.S.	J. E. Ritchie, M.A. .. J. Coull.	6th March, 1922, to 7th Oct., 1922.
2	Bangor	University College of North Wales.	Prof. E. Taylor-Jones, D.Sc.	R. D. Rowlands, B.Sc.	6th Mar., 1922, to 31st Mar., 1923.
3	Belfast	Municipal College of Technology.	Major R. Stanley, B.A. ..	J. Melia .. .. .. C. Wood.	6th Mar., 1922, to 29th July, 1922.
4	Birmingham ..	The University	Prof. S. W. J. Smith, F.R.S.	R. T. Ashford, B.Sc. .. W. G. Darvell, M.Sc. A. R. Smith, B.Sc. E. Tyler, B.Sc.	28th Mar., 1922, to 30th June, 1923.
5	Bristol	The University	Prof. A. M. Tyndall, D.Sc.	M. G. Bennett, M.Sc. .. F. N. Dight, B.Sc. G. B. Grindlay, B.Sc.	6th Mar., 1922, to 30th June, 1923.
6	Cambridge ..	The University	E. V. Appleton, M.A., D. Sc.	W. T. Gibson, B.A. .. R. S. Barker.	6th Mar., 1922, to 17th June, 1922.
7	Newcastle ..	Armstrong College ..	Prof. G. W. Todd, D.Sc...	W. Faid, M.Sc. .. .. H. Oyston, M.Sc. R. Davis, B.Sc.	6th Mar., 1922, to 30th June, 1923.
8	Peterborough ..	P.O. Experimental Station	N. P. Hinton, B.Sc. ..	W. F. Lowe	8th May, 1922, to 9th Dec., 1922.
9	Slough	Radio Research Board Station.	R. L. Smith-Rose, Ph.D., M.Sc.	S. R. Chapman, M.Sc.	6th Mar. to 6th May, 1922.
10	Teddington ..	National Physical Laboratory	R. L. Smith-Rose, Ph.D., M.Sc.	R. L. Smith-Rose, Ph.D., M.Sc. A. C. Haxton.	6th Mar. to 11th Nov., 1922.
11	Lerwick ..	Air Ministry, Wireless Station.	R. L. Smith-Rose, Ph.D., M.Sc.	L. W. Scoggins .. .. L. G. Johnson.	30th July, 1923, to 19th April, 1924.

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VARIATIONS OF APPARENT BEARINGS OF RADIO TRANSMITTING STATIONS

PART II—OBSERVATIONS ON FIXED STATIONS MARCH, 1922–APRIL, 1924

SECTION I.—INTRODUCTORY AND STATEMENT OF RESULTS OBTAINED TO MARCH, 1923

(1) *Continuation of Investigation*

PART I of the report on this investigation dealt with the observations obtained up to the beginning of March, 1922. Prior to that date the observations were restricted to transmissions on damped waves and such undamped waves as could be taken on the "spark" receiver without heterodyne. At the commencement of the second year of observations the direction-finding stations were equipped for undamped wave reception by means of screened oscillators. The necessity for the employment of a screened oscillator and the details of its design have already been given in a previous publication.(1)*

The daily observations were continued in the same manner as previously over the period 6th March, 1922, to 31st March, 1923, with the following observation periods :—

	Morning Period.	Evening Period.
1st week	0800 to 0930	1630 to 1800
2nd week	0900 to 1030	1800 to 1930
3rd week	1000 to 1130	1900 to 2030
4th week	1100 to 1230	2000 to 2200

Towards the end of January, 1923, a series of 24-hour tests was commenced in which three observing stations participated, and these tests were continued after the cessation of the daily observations until 30th June, 1923.

From the 30th July, 1923, to 19th April, 1924, observations were also carried out at a station at Lerwick, Shetland Islands, to study conditions in Northern Latitudes.

Apart from this, the only change made in the location of the stations was the opening of the Birmingham University station in place of the Leeds station, and an amended list of the stations and personnel is given on the opposite page.

* These numbers refer to the Bibliography on p. 107.

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(2) *Statement of Results obtained*

During this second year of the daily observations the number of results collected for reduction, after a critical examination in which all doubtful* readings were neglected, was over 104,000. The distribution of these results among the different stations is as follows :—

Station.	Total number of observations collected between 6th March, 1922, and 31st March, 1923.
Aberdeen	.. 8,611
Bangor	.. 26,238
Belfast	.. 2,002
Birmingham	.. 16,658
Bristol	.. 11,265
Cambridge	.. 2,566
Newcastle	.. 19,408
Peterborough	.. 6,479
Slough	.. 1,142
Teddington	.. 10,241
	104,610

The abnormally low number of readings obtained at a few of the stations is accounted for by the fact that these were not in operation during the whole year.

A summary of all these results in the same form as adopted in Part I of the report is set out in Tables 1 to 10. With the conversion of the stations to continuous wave working, a large number of new transmitting stations were brought within the range of the direction-finder sets, and the distribution of these with the station previously observed is given on the gnomonic chart at the end of this report (Fig. 31).

For the purpose of tabulating and discussing the results, the arbitrary division of the times of observation into day and night periods has been adopted in the same manner as in Part I of the Report. The normal " night " period is assumed to extend from one hour before sunset at the easterly end to one hour after sunrise at the westerly end of the path of transmission.

* The principal reasons for rejection of readings were uncertainty in the identification of the transmitting station by the observers and the occasional heavy interference, which considerably reduced the reliability of some observations.

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TABLE 1.—*Summary of Observations taken at Aberdeen from 6th March, 1922, to 7th October, 1922*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	I.†	4·6	299·2	254	1·5	+ 11·4	156	2·1	+ 11·5
Air Ministry	C.W. 4·1	0800–0930 1900–2030	402	167·0	98	6·9	− 2·2	102	7·0	− 1·3
Chelmsford	C.W. 3·8	I.	389	163·6	151	2·0	+ 0·1	182	2·4	+ 1·4
Cleethorpes	C.W. 4·3	I.	263	161·5	38	7·0	+ 0·1	—	—	—
Clifden	S. 5·8	0950 2150	402	233·9	19	3·0	− 10·7	35	6·8	− 11·0
Clifden	C.W. 5·8	I.	402	233·9	189	5·0	− 10·9	573	4·1	− 11·0
Coltano	S. 4·2	I.	1,080	144·5	52	2·0	+ 7·9	41	1·7	+ 8·1
Karlsborg	S. 2·5	2000	615	74·5	—	—	—	259	32·3	+ 7·6
Karlsborg	S. 4·2	I.	615	74·5	97	8·6	+ 7·3	44	7·5	+ 5·0
Karlsborg	C.W. 3·9	I.	615	74·5	436	4·8	+ 1·2	242	34·3	+ 2·3

* Termed "Total Variation" in Part I. † I. = Irregular transmission.

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TABLE 1.—*Summary of Observations taken at Aberdeen from 6th March, 1922, to 7th October, 1922*—continued

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Moscow	S. 4·8	I.†	1,498	76·8	—	—	—	185	4·2	+ 5·7
Nauen	S. 3·2	1150	670	111·4	66	2·3	+ 14·9	—	—	—
Nauen	C.W. 4·7	I.	670	111·4	553	2·9	+ 14·2	388	7·0	+ 14·1
Ongar (GLA)	C.W. 2·9	I.	388	164·5	35	3·1	− 0·5	23	3·5	− 0·4
Ongar (GLB)	C.W. 3·8	I.	388	164·5	536	3·1	+ 0·5	511	4·3	+ 0·4
Ongar (GLO)	C.W. 4·4	I.	388	164·5	172	5·9	+ 1·1	477	6·5	+ 1·3
Paris, (FL)	S. 2·6	0815	601	160·6	186	1·7	+ 0·8	—	—	—
Paris, (FL)	S. 2·6	0920	601	160·6	574	1·6	+ 0·7	429	1·4	+ 0·8
Paris, (FL)	S. 2·6	1920 1130	601	160·6	175	1·6	+ 1·0	70	1·1	+ 1·0
Paris, (FL)	S. 3·2	2155 1200	601	160·6	59	1·4	+ 1·4	—	—	—
Poldhu	S. 2·8	0950	509	196·1	31	0·8	− 13·4	29	6·2	− 13·2
Stonehaven	C.W. 4·5	2150 I.	16·1	204·0	417	3·3	− 13·0	351	4·5	− 12·4
Stonehaven	C.W. 5·5	I.	16·1	204·0	112	4·7	− 10·5	—	—	—

* Termed "Total Variation" in Part I. I = Irregular transmission.

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TABLE 2.—*Summary of Observations taken at Bangor from 6th March, 1922, to 31st March, 1923*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	0830–0930 1700	284	14·7	93	4·2	+ 3·8	67	31·0	+ 3·7
Aberdeen	C.W. 3·3	2100	284	14·7	—	—	—	35	29·0	+ 3·3
Air Ministry	C.W. 4·1	I.†	212	123·4	176	18·7	— 6·4	131	41·7	— 5·1
Aranjuez	C.W. 3·7	I.	912	176·5	671	12·6	+ 4·3	586	57·4	+ 5·4
Berne	C.W. 3·4	I.	668	125·6	774	15·3	— 1·5	323	50·8	+ 1·5
Budapest	C.W. 4·3	I.	1,488	101·9	444	6·9	— 7·4	281	45·0	— 7·8
Chelmsford	C.W. 3·8	I.	218	116·3	132	3·2	— 2·7	103	15·8	— 2·6
Cleethorpes	C.W. 4·3	0800	168	81·8	73	20·6	— 10·2	—	—	—

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 2.—*Summary of Observations taken at Bangor from 6th March, 1922, to 31st March, 1923*—continued

(1)	(2)	(3)	(4)	5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Cleethorpes	C.W. 4·3	I.†	168	81·8	51	10·4	— 11·7	115	48·7	— 10·0
Clifden	S. 5·8	0950	244	275·9	60	1·9	— 0·4	—	—	—
Clifden	C.W. 5·8	I.	244	275·9	344	3·5	— 1·2	469	56·1	+ 0·5
Coltano	S. 4·2	I.	935	129·3	104	8·6	— 3·0	140	44·8	— 3·6
Horsea	C.W. 5·0	I.	208	141·1	69	13·3	— 1·7	48	20·3	— 1·1
Karlsborg	S. 2·5	1215	803	55·7	32	2·8	— 9·5	257	34·4	— 6·8
Karlsborg	S. 4·2	2000 I.	803	55·7	42	1·6	— 4·5	29	11·1	— 1·2
Karlsborg	C.W. 3·9	I.	803	55·7	540	10·8	— 5·2	291	51·1	— 4·1
Karlsborg	C.W. 4·3	I.	803	55·7	260	29·1	— 4·4	191	34·5	+ 0·4

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Konigswusterhausen	C.W. 5·2	I.	743	87·8	1101	9·2	− 5·9	340	60·5	− 4·1
Leafield (M.)	C.W. 8·8	1200 2000	144	130·9	277	26·2	− 1·1	552	65·7	− 2·3
Leafield (S.)	C.W. 8·7	1200 2000	144	130·9	277	28·6	− 1·2	550	40·8	− 2·3
Lyngby (M.)	C.W. 3·7	I.	686	68·6	45	7·0	− 9·0	69	32·0	− 3·8
Lyngby (S.)	C.W. 3·6	I.	686	68·6	53	7·7	− 8·5	64	45·1	− 2·2
Malta	C.W. 4·2	I.	1,498	135·6	110	5·3	− 2·1	—	—	—
Moscow	S. 4·8	I.	1,658	67·1	121	2·4	− 6·6	361	26·6	− 3·4
Nantes	S. 2·5	0800 2100	430	164·8	18	3·5	+ 7·1	48	7·7	+ 6·8
Nantes	S. 4·2	0810 2130	430	164·8	51	3·6	+ 1·4	41	6·5	+ 1·4
Nantes	S. 2·5	1230	430	164·8	70	5·0	+ 6·2	—	—	—
Nauen	S. 3·2	1150	708	86·3	158	3·1	− 11·7	—	—	—
Nauen	C.W. 4·7	I.	708	86·3	752	24·9	− 11·3	902	60·5	− 11·1
Nauen	C.W. 6·3	I.	708	86·3	472	11·8	− 2·7	756	38·5	− 4·6
Northolt (M.)	C.W. 7·0	I.	196	124·7	171	13·1	− 5·8	186	38·5	− 5·7
Northolt (S.)	C.W. 6·9	I.	196	124·7	171	14·9	− 5·8	186	33·8	− 5·8

* Termed "Total Variation" in Part I.

† I = Irregular transmission.

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TABLE 2.—*Summary of Observations taken at Bangor from 6th March, 1922, to 31st March, 1923*—continued

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Ongar, GLA.	C.W. 2·9	I.†	210	118·0	861	20·8	— 5·6	563	62·1	— 4·2
Ongar, GLB.	C.W. 3·8	I.	210	118·0	973	24·8	— 1·4	461	48·2	— 0·7
Ongar, GLO.	C.W. 4·4	I.	210	118·0	847	21·4	— 5·3	1,057	48·1	— 5·0
Paris FL	S. 2·6	0815	410	134·8	137	2·6	— 1·8	—	—	—
Paris, FL.	S. 2·6	0920 1920	410	134·8	895	4·8	— 1·9	108	16·6	— 0·7
Paris, FL.	S. 2·6	1130	410	134·8	135	2·9	— 1·8	—	—	—
Paris, FL.	S. 3·2	1200	410	134·8	74	1·8	+ 0·2	—	—	—
Paris, (M.)	C.W. 7·6	I.	410	134·8	294	14·2	— 3·8	237	52·4	— 2·7
Paris, (S.)	C.W. 7·5	I	410	134·8	294	10·9	— 4·2	231	53·6	— 3·3

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Pembroke	C.W. 4·8	I.	112	198·9	23	3·5	+ 3·6	48	13·9	+ 3·3
Poldhu	S. 2·8	0950 2150	228	193·0	14	0·5	+ 2·8	10	2·9	+ 1·6
Poldhu	S. 2·8	I.	228	193·0	12	1·9	+ 4·0	41	17·8	+ 4·6
Rome (M)	C.W. 5·4	I.	1,498	128·9	79	7·1	− 5·0	343	41·9	− 8·4
Rome (S)	C.W. 5·4	I.	1,498	128·9	79	9·3	− 5·1	344	46·9	− 8·3
Stonehaven	C.W. 4·5	I.	266	15·0	673	17·0	− 0·9	552	44·0	− 0·4
Stonehaven	C.W. 5·3	I.	266	15·0	300	4·4	+ 1·1	—	—	—
Tours M.	C.W. 6·8	I.	455	150·3	238	6·0	+ 0·8	249	31·5	+ 0·6
Tours S.	C.W. 6·6	I.	455	150·3	238	14·5	+ 0·9	252	29·0	0·0
Whitehall	C.W. 3·3	1700	206	123·6	—	—	—	27	19·9	− 0·6
Whitehall	C.W. 3·3	2100	206	123·6	—	—	—	25	32·8	+ 2·2

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 3.—*Summary of Observations taken at Belfast from 6th March, 1922, to 29th July, 1922*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Air Ministry	C.W. 4·1	I.†	328	129·0	38	4·5	— 1·3	—	—	—
Cleethorpes	C.W. 4·3	0800	250	104·7	31	2·0	+ 2·1	—	—	—
Cleethorpes	C.W. 4·3	I.	250	104·7	53	6·5	+ 1·2	33	9·5	+ 2·2
Clifden	S. 5·8	0950	184	246·1	42	1·5	+ 1·9	—	—	—
Clifden	C.W. 5·8	I.	184	246·1	156	6·0	+ 5·9	145	11·5	+ 5·2
Coltano	S. 4·2	I.	1,052	129·2	15	2·5	+ 2·6	55	7·0	+ 4·0
Karlsborg	S. 2·5	2000	803	62·6	—	—	—	40	11·0	+ 4·4
Karlsborg	S. 4·2	I.	803	62·6	33	3·0	+ 0·4	33	12·0	+ 0·9
Moscow	S. 4·8	I.	1,658	69·1	—	—	—	122	6·5	+ 5·2

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Nantes	S.	4·2	0810	430	158·5	29	1·5	− 0·3	—	—	—
Nauen	S.	3·2	1150	708	92·2	19	1·5	+ 1·4	—	—	—
Nauen	C.W.	4·7	I.	708	92·2	136	5·5	+ 3·6	78	13·5	+ 6·8
Nauen	C.W.	6·3	I.	708	92·2	47	2·0	+ 1·5	21	2·0	+ 2·2
Ongar	C.W.	4·4	I.	210	126·0	80	6·5	+ 2·5	25	2·5	+ 2·7
Paris	S.	2·6	0815	410	135·1	134	5·5	+ 4·2	—	—	—
Paris	S.	2·6	0920	410	135·1	247	5·0	+ 3·9	129	7·0	+ 4·6
Paris	S.	2·6	1920 1130	410	135·1	93	3·0	+ 4·2	—	—	—
Paris	S.	3·2	1200	410	135·1	85	2·0	− 2·3	—	—	—
Poldhu	S.	2·8	0950	228	174·6	38	5·0	+ 4·6	—	—	—

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 4.—*Summary of Observations taken at Birmingham from 28th March, 1922, to 31st March, 1923*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Air Ministry	C.W. 4·1	I.†	130	128·6	542	13·0	+ 1·7	382	20·4	+ 1·7
Chelmsford	C.W. 3·8	I.	113	115·1	198	5·4	+ 2·3	152	18·5	+ 3·5
Clifden	S. 5·8	0950	343	284·8	71	1·4	+ 2·2	—	—	—
Coltano	S. 4·2	I.	830	132·2	71	6·0	+ 0·7	94	7·0	+ 1·4
Horsea	C.W. 5·0	I.	117	162·0	381	5·5	− 0·2	323	9·0	− 0·3
Karlsborg	S. 2·5	1215	762	50·4	136	5·8	+ 0·6	438	47·5	+ 4·3
Karlsborg	S. 4·2	2000 I.	762	50·4	58	3·6	+ 0·6	25	4·5	+ 1·3
Karlsborg	C.W. 3·9	I.	762	50·4	104	9·3	+ 1·7	38	7·5	+ 2·5
Konigswusterhausen..	C.W. 5·2	I.	657	84·7	86	7·4	+ 2·4	36	23·0	− 0·7

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Moscow	S.	4·8	I.	1,596	66·0	473	9·0	+	0·9	394	17·3	+ 2·3
Nantes	S.	2·5	0800 2100	364	178·3	55	3·3	−	2·4	98	8·3	− 2·0
Nantes	S.	4·2	0810 2130	364	178·3	111	4·3	−	1·9	103	7·0	− 2·4
Nauen	S.	3·2	1150	621	82·8	226	6·1	+	3·4	—	—	—
Nauen	C.W.	4·7	I.	621	82·8	744	14·5	+	3·9	506	21·0	+ 4·0
Ongar (GLA) ..	C.W.	2·9	I.	104	119·0	1786	10·8	+	2·1	940	21·0	+ 2·0
Ongar (GLB) ..	C.W.	3·8	I.	104	119·0	1242	11·0	+	2·4	540	21·7	+ 2·4
Ongar (GLO) ..	C.W.	4·4	I.	104	119·0	1089	11·9	+	2·5	615	15·6	+ 2·7
Paris (FL)	S.	2·6	0815	189	141·6	300	2·5	+	2·2	—	—	—
Paris (FL)	S.	2·6	0920 1920	189	141·6	1616	5·2	+	2·4	322	4·3	+ 2·4
Paris (FL)	S.	2·6	1130 2155	189	141·6	399	2·3	+	2·2	29	4·1	+ 1·2
Paris (FL)	S.	3·2	1200	189	141·6	200	1·8	+	0·9	—	—	—

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 5.—*Summary of Observations taken at Bristol from 6th March, 1922, to 31st March, 1923*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	0830–0930 1700	395	2·4	82	8·5	+ 3·4	64	20·2	+ 4·2
Air Ministry	C.W. 4·1	0800–0930 1900–2030	112	88·6	314	17·8	− 2·6	266	31·0	− 2·3
Aranjuez	C.W. 3·7	I.†	789	181·8	239	6·5	+ 5·3	140	41·3	+ 8·3
Chelmsford	C.W. 3·8	I.	133	80·2	79	2·7	− 2·6	49	5·1	− 2·1
Clifden	S. 5·8	0950 2150	341	296·7	19	0·7	− 1·2	32	6·2	− 3·0
Clifden	C.W. 5·8	I.	341	296·7	166	5·6	− 1·1	212	3·9	− 1·2
Coltano	S. 4·2	I.	809	126·8	43	3·3	− 2·7	34	3·4	− 2·0
Devizes	C.W. 2·1	I.	28·6	103·0	35	9·0	− 4·1	101	11·2	− 5·9
Horsea	C.W. 5·0	I.	78	122·9	187	9·0	− 1·8	151	18·9	− 2·5

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Karlsborg	S.	2·5	1215 2000	828	47·6	27	5·2	−	0·1	324	41·0	+ 2·5
Karlsborg	C.W.	3·9	I.	828	47·6	84	2·5	+	1·3	23	11·9	+ 1·1
Karlsborg	C.W.	4·3	I.	828	47·6	92	20·0	+	2·9	33	32·8	+ 1·4
Konigswusterhausen	C.W.	5·2	I.	695	78·8	464	8·2	−	1·5	78	28·5	− 2·0
Leafield (M)	C.W.	8·7	1200 2000	51	60·3	215	7·3	−	0·9	480	13·0	− 1·0
Leafield (S)	C.W.	8·6	1200 2000	51	60·3	169	7·4	−	0·8	378	15·8	− 0·7
Moscow	S.	4·8	I.	1,651	63·8	45	4·5	−	0·2	232	20·0	+ 1·0
Nantes	S.	2·5	0800 2100	298	172·0	35	6·6	+	2·2	83	3·0	+ 2·3
Nantes	S.	4·2	0815 2130	298	172·0	91	2·8	+	2·0	74	4·5	+ 2·0
Nauen	S.	3·2	1150	662	76·8	182	2·8	−	1·5	—	—	—
Nauen	C.W.	4·7	I.	662	76·8	454	16·4	−	2·1	548	67·2	− 3·2
Nauen	C.W.	6·3	I.	662	76·8	22	5·7	−	1·0	54	31·3	− 4·0
Northolt (M)	C.W.	7·0	I.	88	85·0	50	3·9	−	2·9	49	27·2	− 3·9
Northolt (S)	C.W.	6·9	I.	88	85·0	49	5·8	−	2·6	49	31·0	− 3·3
Ongar (GLA) ..	C.W.	2·9	I.	120	81·1	251	13·8		0·0	246	63·0	− 2·3
Ongar (GLB) ..	C.W.	3·8	I.	120	81·1	588	15·5	−	1·3	335	35·8	− 1·5
Ongar (GLO) ..	C.W.	4·4	I.	120	81·1	287	9·3	−	2·3	321	44·9	− 1·3

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 5.—*Summary of Observations taken at Bristol from 6th March, 1922, to 31st March, 1923*—continued

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting stations.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Paris (FL)	S. 2·6	0815	189	127·8	158	2·2	— 0·6	—	—	—
Paris (FL)	S. 2·6	0920 1920	189	127·8	900	4·1	— 0·6	193	4·5	— 0·6
Paris (FL)	S. 2·6	1130 2155	189	127·8	174	2·7	— 0·8	64	11·5	— 1·0
Paris (FL)	S. 3·2	1200	189	127·8	88	1·7	— 1·0	—	—	—
Paris (M)	C.W. 7·5	I.†	189	127·8	41	5·7	— 1·6	—	—	—
Paris (S)	C.W. 7·4	I.	189	127·8	35	6·9	— 1·4	—	—	—
Paris (UFP)	C.W. 2·4	I.	189	127·8	98	17·2	+ 4·7	73	25·7	+ 2·9
Poldhu	S. 2·8	0950 2150	152	230·6	25	1·2	— 0·8	8	14·6	— 5·1
Stonehaven	C.W. 4·5	I.	378	1·8	166	8·4	+ 4·8	88	27·0	+ 6·5
Whitehall	C.W. 3·3	0900 1700	106	89·0	113	13·7	— 2·2	53	19·7	— 1·0

* Termed "Total Variation" in Part I. † I. = Irregular transmission.

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TABLE 6.—*Summary of Observations taken at Cambridge from 6th March, 1922, to 17th June, 1922*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Berne	C.W. 3·4	I.†	486	134·6	41	1·9	0·0	39	2·2	+ 0·1
Chelmsford	C.W. 3·8	I.	35·4	153·3	207	3·0	— 1·0	166	6·5	— 0·8
Clifden	C.W. 5·8	I.	430	285·6	33	0·4	— 1·1	59	1·1	— 1·1
Coltano	S. 4·2	I.	757	137·2	—	—	—	60	9·0	+ 0·1
Karlsborg	S. 2·5	1215 2000	709	46·7	10	1·5	+ 0·6	120	59·0	+ 9·9
Karlsborg	S. 4·2	I.	709	46·7	22	3·5	+ 0·3	25	13·4	+ 6·0
Karlsborg	C.W. 3·9	I.	709	46·7	46	2·0	+ 1·0	27	0·5	+ 0·5
Moscow	S. 4·8	I.	1,526	65·8	—	—	—	30	7·0	+ 2·3
Nantes	S. 2·5	0800 2100	348	194·0	19	4·4	— 1·3	36	17·5	+ 0·3

* Termed "Total Variation" in Part I.

†I. = Irregular transmission.

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TABLE 6.—*Summary of Observations taken at Cambridge from 6th March, 1922, to 17th June, 1922*—continued

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Nantes	S. 4·2	0810 2130	348	194·0	22	2·0	+ 0·2	38	16·0	− 1·2
Nauen	S. 3·2	1150	535	81·7	56	1·5	+ 1·1	—	—	—
Nauen	C.W. 4·7	I.†	535	81·7	43	1·6	+ 1·5	24	14·6	+ 3·7
Ongar (GLA)	C.W. 2·9	I.	34	174·0	218	3·0	+ 0·4	160	10·0	+ 0·4
Paris (FL)	S. 2·6	0815	250	156·4	85	1·4	− 0·8	—	—	—
Paris (FL)	S. 2·6	0920 1920	250	156·4	332	1·7	− 0·8	144	4·3	− 0·7
Paris (FL)	S. 2·6	1130	250	156·4	62	2·3	− 0·9	—	—	—
Paris (FL)	S. 3·2	1200	250	156·4	66	0·9	+ 0·1	—	—	—
Paris (UFP)	C.W. 2·4	I.	250	156·4	55	3·0	− 0·7	44	7·0	− 0·8
Poldhu	S. 2·8	0950 2150	275	239·0	19	1·8	+ 1·1	21	27·0	− 4·8

* Termed "Total Valuation" in Part I. † I. = Irregular transmission.

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TABLE 7.—*Summary of Observations taken at Newcastle from 6th March, 1922, to 31st March, 1923*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	0830–0930 1700	154	352·0	189	17·5	+ 0·7	125	33·8	+ 0·8
Aberdeen	C.W. 3·3	2100	154	352·0	—	—	—	111	37·2	+ 0·5
Air Ministry	C.W. 4·1	I.†	252	162·5	247	10·3	— 1·2	252	30·7	— 0·8
Berne	C.W. 3·4	I.	676	140·8	530	5·1	— 1·5	217	56·0	— 0·6
Budapest	S. 3·0	I.	1,026	111·6	48	4·0	— 2·0	26	7·1	0·0
Chelmsford	C.W. 3·8	I.	240	158·1	76	4·4	— 1·6	70	2·5	— 1·9
Cleethorpes	C.W. 4·3	0800	118	147·2	118	12·0	— 1·5	—	—	—
Cleethorpes	C.W. 4·3	I.	118	147·2	116	8·5	— 2·3	187	21·0	— 0·3

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 7.—*Summary of Observations taken at Newcastle from 6th March, 1922, to 31st March, 1923*—continued

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Clifden	S. 5·8	0950 2150	355	256·2	85	1·5	— 1·4	66	12·5	— 2·5
Clifden	C.W. 5·8	I.†	355	256·2	316	2·3	— 0·5	594	26·0	— 0·4
Coltano	S. 4·2	I.	948	140·6	169	3·3	— 1·9	244	10·8	— 1·6
Horsea	C.W. 5·0	I.	287	175·5	193	13·6	— 0·8	98	15·6	— 1·3
Karlsborg	S. 2·5	1215 2000	650	62·4	171	6·6	+ 0·1	485	57·5	+ 5·1
Karlsborg	S. 4·2	I.	650	62·4	125	6·2	— 0·5	53	26·3	+ 0·1
Karlsborg	C.W. 3·9	I.	650	62·4	503	10·5	+ 2·2	237	55·0	+ 3·8
Konigswusterhausen	C.W. 5·2	I.	658	100·0	501	8·3	— 2·6	260	32·4	— 3·3
Moscow	S. 4·8	I.	1,521	71·8	421	5·5	— 1·6	945	39·0	— 0·8

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Nantes	S.	2·5	0800 2100	538	180·4	21	0·6	− 0·8	94	11·9	− 0·2
Nantes	S.	4·2	0810 2130	538	180·4	84	4·5	− 0·2	93	15·7	− 1·0
Nantes	S.	2·5	1215	538	180·4	60	5·2	− 2·4	—	—	—
Nauen	S.	3·2	1150	612	99·2	250	4·0	− 2·8	—	—	—
Nauen	C.W.	4·7	I.	612	99·2	1421	87·0	− 2·5	1471	78·2	− 0·8
Ongar (GLA) ..	C.W.	2·9	I.	238	160·2	904	11·0	− 0·1	979	59·5	− 0·2
Ongar (GLB) ..	C.W.	3·8	I.	238	160·2	1239	7·5	− 0·8	859	34·4	− 1·2
Ongar (GLO) ..	C.W.	4·4	I.	238	160·2	252	9·5	− 1·4	321	23·9	− 1·7
Paris	S.	2·6	0815	454	156·9	277	2·4	− 2·8	—	—	—
Paris	S.	2·6	0920 1920	454	156·9	1486	5·5	− 3·1	432	5·8	− 2·7
Paris	S.	2·6	1130 2155	454	156·9	516	2·4	− 2·7	162	13·2	− 4·0
Paris	S.	3·2	1200	454	156·9	114	1·5	− 1·1	—	—	—
Poldhu	S.	2·8	0950 2150	374	205·6	42	2·9	+ 0·4	37	30·0	− 1·9
Sofia	S.	3·2	I.	1,400	116·8	—	—	—	163	48·0	− 1·8
Whitehall	C.W.	3·3	0900 1700	247	164·9	43	6·9	+ 0·9	37	7·1	+ 1·8
Whitehall	C.W.	3·3	2100	247	164·9	—	—	—	30	12·0	− 0·3

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 8.—*Summary of Observations taken at Peterborough, from 8th May, 1922, to 9th December, 1922*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	0830	326	347·0	40	3·0	+ 2·0	23	10·0	+ 4·7
Air Ministry	C.W. 4·1	1700 I.†	79	171·8	88	2·5	+ 1·8	80	14·2	+ 2·2
Budapest	S. 4·0	I.	921	104·8	18	2·0	+ 1·2	55	9·0	+ 2·8
Clifden	S. 5·8	0950	410	282·1	18	1·7	+ 1·5	33	22·8	− 3·4
Karlsborg	S. 2·5	2150 1215	700	48·8	25	4·5	− 0·2	229	61·0	+ 4·1
Konigswusterhausen	C.W. 5·2	2000 I.	585	86·3	286	6·2	+ 0·6	46	5·2	+ 1·1
Leafield (M)	C.W. 8·7	1200	77	227·2	90	22·7	+ 2·1	224	75·5	+ 0·3
Leafield (S)	C.W. 8·6	2000 1200	77	227·2	90	21·5	+ 2·5	225	99·5	+ 2·2
Moscow	S. 4·8	2000 I.	1,527	66·7	137	4·0	− 0·6	206	27·3	0·0

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Nantes	S.	2·5	0800 2100	380	190·4	11	2·0	+ 0·2	37	12·7	+ 1·3
Nantes	S.	4·2	0815 2130	380	190·4	36	4·5	+ 0·4	42	21·5	+ 1·5
Nauen	S.	3·2	1150	550	84·3	96	6·0	− 0·6	—	—	—
Nauen	C.W.	4·7	I.	550	84·3	132	17·0	− 0·2	165	50·0	+ 5·9
Nauen	C.W.	6·3	I.	550	84·3	112	6·0	− 0·6	92	42·5	+ 1·7
Ongar (GLA) ..	C.W.	2·9	I.	64	160·5	289	5·0	+ 4·0	173	24·7	+ 4·0
Ongar (GLB) ..	C.W.	3·8	I.	64	160·5	319	3·7	+ 4·3	166	16·5	+ 4·8
Ongar (GLO) ..	C.W.	4·4	I.	64	160·5	329	9·0	+ 4·6	326	21·0	+ 5·8
Paris (FL)	S.	2·6	0815	281	155·8	111	2·3	+ 0·4	—	—	—
Paris (FL)	S.	2·6	0920 1920	281	155·8	601	3·2	+ 0·5	208	5·2	+ 0·6
Paris (FL)	S.	2·6	1130 2155	281	155·8	139	2·0	+ 0·6	35	4·5	0·0
Paris (FL)	S.	3·2	1150	281	155·8	36	1·0	+ 1·6	—	—	—
Paris (UFP)	C.W.	2·4	I.	281	155·8	178	5·5	− 1·3	113	37·5	− 1·3
Stonehaven	C.W.	4·5	I.	310	345·6	201	14·3	+ 1·5	22	14·2	− 0·2
Whitehall	C.W.	3·3	0900 1700	75	176·2	48	4·5	+ 1·4	33	7·5	+ 1·1

* Termed "Total Variation" in Part I.

* I. = Irregular transmission.

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TABLE 9.—*Summary of Observations taken at Slough from 6th March, 1922, to 6th May, 1922*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Chelmsford	C.W. 3·8	I.†	47·5	69·9	18	5·4	— 2·9	12	6·2	— 1·5
Coltano	S. 4·2	I.	742	132·5	90	7·8	+ 0·6	61	13·0	+ 1·8
Karlsborg	S. 2·5	2000	764	44·9	—	—	—	64	31·8	— 3·5
Karlsborg	S. 4·2	I.	764	44·9	51	1·9	— 1·5	—	—	—
Moscow	S. 4·8	I.	1,572	64·2	—	—	—	75	7·5	— 0·2
Nauen	S. 3·2	1150	576	76·7	35	4·0	— 0·7	—	—	—
Paris (FL)	S. 2·6	0815	221	143·9	50	1·3	+ 1·0	—	—	—
Paris (FL)	S. 2·6	0920 1920	221	143·9	160	1·4	+ 0·8	49	1·8	+ 1·0
Paris (FL)	S. 2·6	1130	221	143·9	52	0·4	+ 0·9	—	—	—
Paris (FL)	S. 3·2	1200	221	143·9	57	0·3	+ 1·1	—	—	—
Poldhu	S. 2·8	0950 2150	228	245·7	46	1·4	0·0	22	19·8	— 2·2
Whitehall	C.W. 3·3	I.	18	87·0	41	3·8	— 0·3	20	1·2	— 0·5

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 10.—*Summary of Observations taken at Teddington from 6th March, 1922, to 11th November, 1922*

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme variation.	Error of mean.	No.	Extreme variation.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Aberdeen	C.W. 3·3	0830–0930 1700 &2100	406	350·1	113	3·0	+ 1·0	83	41·5	— 1·3
Air Ministry	C.W. 4·1	0800–0930 1900–2030	17	79·0	171	6·2	+ 0·3	211	5·3	+ 0·6
Chelmsford	C.W. 3·8	I.†	40·6	58·9	185	6·3	+ 0·2	261	16·4	— 0·2
Clifden	S. 5·8	0950 2150	430	292·8	34	1·5	+ 1·5	62	15·7	+ 2·5
Clifden	C.W. 5·8	I.	430	292·8	153	5·7	+ 1·4	389	38·5	+ 0·3
Coltano	S. 4·2	I.	731	133·0	81	4·3	— 1·2	110	13·7	+ 0·6
Horsea	C.W. 5·0	I.	52	220·2	24	3·5	+ 1·0	21	8·5	+ 1·6
Karlsborg	S. 2·5	2000	760	44·4	—	—	—	152	54·8	+ 3·3

* Termed "Total Variation" in Part I.

† I. = Irregular transmission.

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TABLE 10.—*Summary of Observations taken at Teddington from 6th March, 1922, to 11th November, 1922*—continued

(1)	(2)	(3)	(4)	(5)	(6)			(7)		
Transmitting station.	Type and wave-length.	Time of trans-mission.	Dis-tance.	True bearing.	Day Observations.			Night Observations.		
					No.	Extreme* varia-tion.	Error of mean.	No.	Extreme varia-tion.	Error of mean.
	(km.)		(miles)	(degrees)		(degrees)	(degrees)		(degrees)	(degrees)
Karlsborg	S. 4·2	I.†	760	44·4	27	3·4	+ 0·6	14	11·5	+ 2·5
Konigswusterhausen..	C.W. 5·2	I.	599	78·7	106	5·0	− 0·4	254	45·0	+ 3·1
Leafield (M)	C.W. 8·7	1200 2000	60	298·4	177	9·0	+ 1·9	336	42·0	+ 1·8
Leafield (S)	C.W. 8·8	1200 2000	60	298·4	175	7·5	+ 2·0	339	37·7	+ 0·9
Moscow	S. 4·8	I.	1565	64·0	9	2·0	+ 1·5	176	16·5	+ 2·9
Nantes	S. 2·5	0800 2100	296	192·3	13	2·2	− 0·1	68	6·5	+ 0·3
Nantes	S. 4·2	0810 2130	296	192·3	46	3·8	− 0·2	79	14·0	+ 0·1
Nauen	S. 3·2	1150	575	76·3	137	3·3	+ 2·1	—	—	—
Nauen	C.W. 4·7	I.	575	76·3	381	6·0	+ 1·6	588	89·0	+ 4·4

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Nauen	C.W. 6·3	I.	575	76·3	30	1·0	+ 1·9	43	7·4	+ 2·3
Northolt	C.W. 6·9	I.	9	350·0	79	2·4	+ 5·3	—	—	—
Ongar (GLA)	C.W. 2·9	I.	30	49·0	563	5·1	+ 1·5	536	16·0	+ 1·5
Ongar (GLB)	C.W. 3·8	I.	30	49·0	346	3·5	+ 0·9	287	11·5	+ 0·5
Ongar (GLO)	C.W. 4·4	I.	30	49·0	395	3·2	+ 0·9	474	6·4	+ 0·7
Paris (FL)	S. 2·6	0815	211	145·6	193	2·2	− 0·6	—	—	—
Paris (FL)	S. 2·6	0920	211	145·6	719	3·8	− 0·5	224	4·0	− 0·8
Paris (FL)	S. 2·6	1920 1130	211	145·6	220	3·0	− 0·6	—	—	—
Paris (FL)	S. 3·2	1200	211	145·6	90	3·3	− 0·5	—	—	—
Paris (M)	C.W. 7·6	I.	211	145·6	55	3·0	− 0·3	71	13·3	− 0·8
Paris (S)	C.W. 7·5	I.	211	145·6	53	4·0	− 0·2	69	16·3	− 1·1
Paris (UFP)	C.W. 2·4	I.	211	145·6	41	5·7	− 0·6	66	35·0	− 2·0
Poldhu	S. 2·8	0950	235	247·9	30	1·2	+ 2·6	52	19·5	+ 1·4
Tours (M)	C.W. 6·8	2150 I.	162	170·0	22	2·2	− 0·7	78	3·9	− 0·4
Tours (S)	C.W. 6·6	I.	162	170·0	16	2·3	− 0·9	74	8·0	0·0
Whitehall	C.W. 3·3	0900	10	58·0	102	3·2	+ 0·1	84	4·6	+ 0·1
Whitehall	C.W. 3·3	1700 2100	10	58·0	—	—	—	48	2·8	− 0·1

* Termed "Total Variation" in Part I. † I. = Irregular transmission.

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SECTION II.—DISCUSSION OF RESULTS—DAY OBSERVATIONS

(3) *Permanent Deviations*

The foregoing tables show that in many cases the mean observed bearing of a transmitting station in the day periods is seriously in error. These errors were discussed in detail for each observing station in Part I* and the conclusions there drawn are confirmed by these later results. The most prominent new fact brought to light is that this permanent deviation is unaltered by a change in the type of transmission from damped to undamped waves. There are many illustrations of this fact among the results, although in searching for examples care must be taken to see that the effect has not been masked by a large change in wave-length accompanying the change from damped to undamped waves. As previously noted, the most prominent example of a change in permanent deviation accompanying a change in wave-length occurs at Bangor, where the direction-finder was situated in very mountainous country.

(4) *Variable errors. (Magnitude of errors observed)*

In the previous Part of this report it was observed that in general the day variations of apparent bearing are confined to an extreme of 7°, corresponding to a departure from the mean of 3° to 4°. Of the results being discussed in the present Part of the report, those observations taken in the daytime which show a greater variation than 7° are summarised in Table 11. It will be noticed that in some cases the variations are very seriously in excess of the above limit, ranging up to 29° and also that the variations often occur at several receiving stations on the same transmitter. This shows that the effect is real and not connected with observers' errors, etc.

The notes made in the remarks column show that in nearly one-third of the cases an explanation can be found by extending the "night" period† to cover about two hours after sunrise. This effect is particularly noticeable in the case of those observations taken soon after 0800 during the winter months.

In many other cases large variations are shown to have occurred at periods which were from three to five hours after sunrise, and all such cases are concentrated in the winter months from October to March. Probably the most prominent example of these is that of the observations on Leafield's noon transmissions, when during the same periods extreme variations of 28·6°, 7·4° and 22·7° were recorded at Bangor, Bristol and Peterborough respectively. The increase in the extent of the variation was very sudden at all stations; for example, by omitting the three periods

* See Bibliography (p. 107)—ref. 2, p. 42.
† For definition of "night" period see p. 2.

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in December, January and February, the extreme variation at Bangor is reduced to 5·8° for the remainder of the year. During the above three months the period of observation was at least four hours after sunrise. Further discussion of this particular case will be given in considering the graphs of weekly and daily readings.

In general, therefore, these results confirm the conclusions reached in Part I* of this report that the day variations of apparent bearings can occasionally exceed the average limit of 7°; and the present results indicate that this excess is due to the change from night to day conditions being seriously delayed during the winter months. Under the worst conditions serious variations are experienced at as much as five hours after sunrise in the winter, but no corresponding effects are observed in the summer months. (*See also* Section XIV, p. 87).

TABLE 11.—*Showing Details of the "Day" Variations exceeding 7°*

(1)	(2)	(3)	(4)
Transmitting Station.	Receiving Station.	Extreme Variation. (degrees).	Remarks.
Aberdeen, C.W.	Bristol ..	8·5	Largest variation within one hour after sunrise, 31.3.23.
,, ,,	Newcastle ..	17·5	Within one hour of sunrise.
Air Ministry, C.W.	Bangor ..	18·7	Largest variations within one hour after sunrise, 18.11.22.
,, ,,	Birmingham ..	13·0	Ditto.
,, ,,	Bristol ..	17·8	Ditto, 18.11.22 to 10.3.23.
,, ,,	Newcastle ..	10·3	Ditto.
Aranjuez, C.W.	Bangor ..	12·6	Variations distributed during winter months, but largest w.e. 10.2.23 within one hour after sunrise.
Berne, C. W. ..	,, ..	15·3	Variations largest within 1½ hours of sunrise, w.e. 18.11.22 and 19.12.22.

* See Bibliography (p. 107)—ref. 2, p. 46.

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TABLE 11.—*Showing Details of the "Day" Variations exceeding 7°* —(continued).

(1)	(2)	(3)	(4)
Transmitting Station.	Receiving Station.	Extreme Variation.	Remarks.
		(degrees)	
Cleethorpes, C.W.	Bangor ..	20·6	Variations largest about 1½ hours after sunrise, w.e. 10.3.22.
,, ,,	,, ..	10·4	Ditto, w.e. 23.12.22.
,, ,,	Newcastle ..	12·0	1–2 hours after sunrise, 10.2.23 and 10.3.23.
,, ,,	,, ..	8·5	Errors distributed.
Coltano, S. ..	Bangor ..	8·6	Weekly mean bearing changed 5° during year.
Devizes, C. W.	Bristol ..	9·0	Largest variation, 2–3 hours after sunrise, 13.3.23.
Horsea, C.W. ..	Bangor ..	13·3	Variations largest 1–2 hours after sunrise, w.e. 23.12.22 and 10.2.23.
,, ,, ..	Bristol ..	9·0	Largest variations within 1½ hours of sunrise 20.1.23 and 10.2.23.
,, ,, ..	Newcastle ..	13·6	Largest variations within 2 hours of sunrise 10.2.23 and 17.2.23.
Karlsborg, S.4·2	Aberdeen ..	8·6	Several hours after sunrise.
,, C.W. 3·9	Bangor ..	10·8	Two hours after sunrise, w.e. 23.12.24.
,, C.W. 4·2	,, ..	29·1	Two hours after sunrise, w.e. 20.1.23.
,, C.W. 3·9	Birmingham ..	9·3	Day-to-day variations, w.e. 9.12.22, several hours after sunrise.
,, C.W. 4·2	Bristol ..	20·0	Largest variation nearly 2½ hours after sunrise, 20.1.23.
,, C.W. 3·9	Newcastle ..	10·5	Errors distributed.

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TABLE 11.—*Showing Details of the "Day" Variations exceeding 7°* —(continued).

(1)	(2)	(3)	(4)
Transmitting Station.	Receiving Station.	Extreme Variation.	Remarks.
		(degrees)	
Konigswusterhausen, C.W.	Bangor ..	9·2	Within 2 hours, 23.12.22 and 13.1.23.
,, ,,	Birmingham	7·4	Distributed variations, Jan. to March, 1923.
,, ,,	Bristol ..	8·2	Variations distributed during year.
,, ,,	Newcastle ..	8·3	Ditto.
Leafield, C.W.	Bangor ..	28·6	Worst variations 4 hours after sunrise, w.e. 9.12.22, 6.1.23 and 3.2.23.
,, ,,	Bristol ..	7·4	Largest variations during w.e. 9.12.22, 4 hours after sunrise variation is day to-day one.
,, ,,	Peterborough	22·7	Ditto.
,, ,,	Teddington ..	9·0	Errors all in w.e. 11.11.22, 5 hours after sunrise.
Lyngby ..	Bangor ..	7·7	Change of weekly mean bearings.
Nauen, C.W. 4·7	,, ..	24·9	Worst variations w.e. 18.11.22, 16.12.22 and 23.12.22, *i.e.*, 1–2 hours after sunrise.
,, ,, 6·3	,, ..	11·8	Ditto. Largest variations within 2 hours of sunrise on 23.12.22 and 10.2.23.
,, ,, 4·7	Birmingham	14·5	Largest variation, 18.11.22 and 16.12.22.
,, ,, 4·7	Bristol ..	16·4	
,, ,, 4·7	Newcastle ..	87·0	Largest variations 1–3 hours after sunrise, 18.11.22 and 2.12.22.
,, ,, 4·7	Peterborough	17·0	Ditto.
Northolt ..	Bangor ..	14·9	Greatest variations obtained 3 hours after sunrise, 9.12.22.

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TABLE 11.—*Showing Details of the "Day" Variations exceeding 7°* —(continued).

(1) Transmitting Station.	(2) Receiving Station.	(3) Extreme Variation.	(4) Remarks.
		(degrees)	
Ongar, C.W. 2·9	Bangor	20·8	Worst variations 1-3 hours after sunrise from 18.11.22 to 17.2.23.
,, ,, 3·8	,, ..	24·8	Ditto.
,, ,, 4·4	,, ..	21·4	Ditto, to 10.3.23.
,, ,, 2·9	Birmingham	10·8	Ditto.
,, ,, 3·8	,, ..	11·0	Ditto.
,, ,, 4·4	,, ..	11·9	Ditto.
,, ,, 2·9	Bristol ..	13·8	Largest within 2 hours of sunrise, 17.2.23.
,, ,, 3·8	,, ..	15·5	Variations 3 hours after sunrise 6.1.23, also within 1 hour at 16.12.22.
,, ,, 4·4	,, ..	9·3	Variations distributed from 28.10.22 to 10.3.23.
,, ,, 2·9	Newcastle ..	11·0	Ditto.
,, ,, 3·8	,, ..	7·5	Ditto.
,, ,, 4·4	,, ..	9·5	Ditto.
,, ,, 4·4	Peterborough	9·0	Ditto.
Paris, C.W. 7·6	Bangor ..	14·2	Largest variations 18.11.22 and 16.12.22.
,, ,, 2·4	Bristol ..	17·2	Largest variations within 2 hours of sunrise, 10.2.23 and 10.3.23.
Rome, C.W. ..	Bangor ..	9·3	Weekly mean varies 4°; and largest variations w.e. 9.12.22.
Stonehaven, C.W.	,, ..	17·0	Variations greatest from w.e. 18.11.22 to 10.2.23.
,, ,,	Bristol ..	8·4	Largest variations 3 hours after sunrise w.e. 3.2.23.

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TABLE 11.—*Showing Details of the "Day" Variations exceeding 7°* —(continued).

(1)	(2)	(3)	(4)
Transmitting Station.	Receiving Station.	Extreme Variation.	Remarks.
		(degrees)	
Stonehaven, C.W.	Peterborough	14·3	Largest variations 2–3 hours after sunrise w.e. 2.12.23 and 9.12.23.
Tours, C.W. ..	Bangor ..	14·5	Greatest variations within 1 hour of sunrise, w.e. 13.1.23.
Whitehall, C.W.	Bristol ..	13·7	Largest variations about 1½ hours after sunrise 18.11.22 and 10.2.23.

(5) *Weekly Variation Curves*

For some of the transmitting stations having definite times of daily transmissions, graphic representations of the extreme bearings observed at different receiving stations over periods of one week are shown in Figs. 1–8. These diagrams confirm the conclusions enumerated in the corresponding section of Part I of the report.*

Whereas in general the extreme values of a week's readings differ by from 1° to 2°, there are at intervals larger variations ranging up to about 6°. In Figs. 5 and 6 also some abnormally large variations up to nearly 20° are shown for the two transmitting stations, Air Ministry and Leafield respectively. These have already been referred to in Table 11 and in the discussion thereon in the previous section. It is noteworthy that there is a marked increase in the extent of the variations during the months November to February. In the case of the Air Ministry station the time of transmission was closely related to sunrise, whereas Leafield's transmissions took place several hours after sunrise. Although the variations recorded at Bangor are not so excessive as during the previous year, the observations taken at these stations are still of a more erratic nature than those taken elsewhere. It is to be seen from Fig. 4 also that the bearing of Nauen at Bangor still remained at the low value to which it dropped in the previous October.†

* See Bibliography (p. 107)—ref. 2, p. 48.
† ditto ditto —ref. 2, fig. 6 (p. 51).

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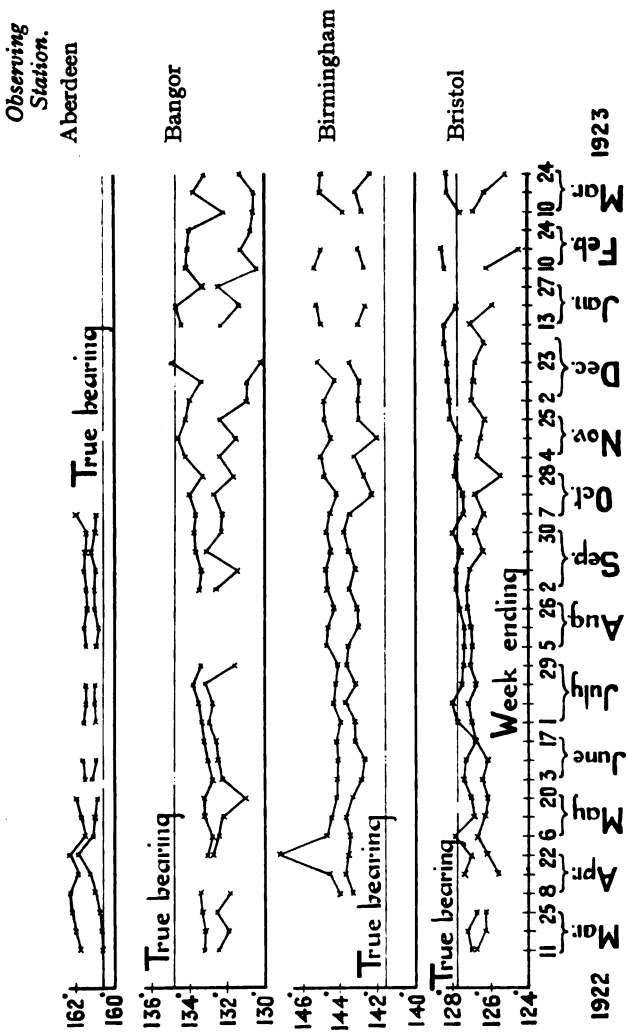

FIG. 1A.—Graphs of Weekly Extreme Bearings of Paris (Damped Waves, $\lambda = 2 \cdot 6$ k.m.), at the 0920 Transmissions.

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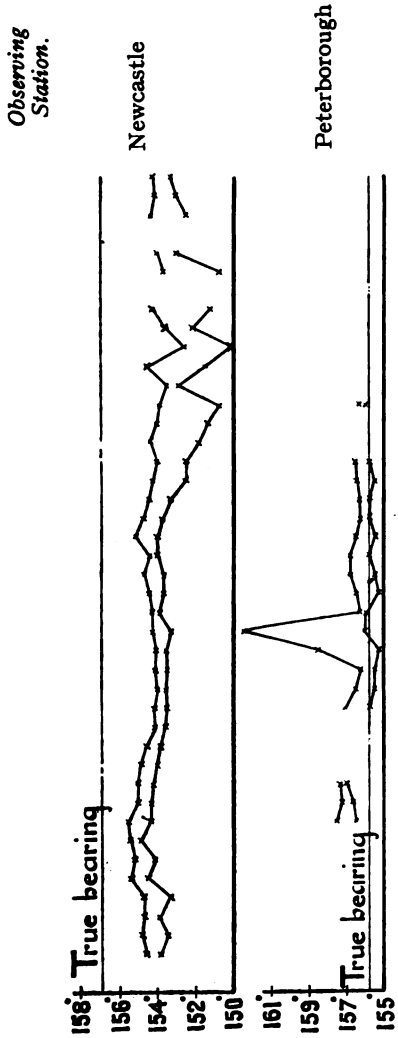

FIG. 1B.—Graphs of Weekly Extreme Bearings of Paris (Damped Waves, $\lambda = 2{\cdot}6$ k.m.), at the 0920 Transmissions.

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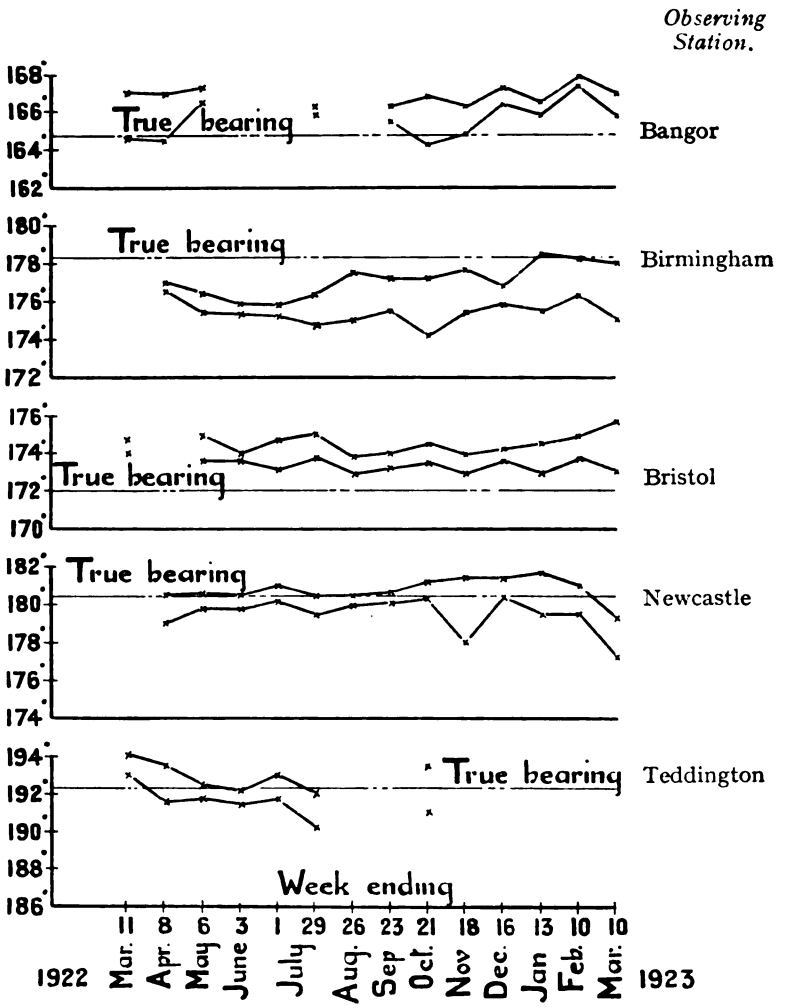

FIG. 2.—Graphs of Weekly Extreme Bearings of Nantes (Damped Waves, $\lambda = 4 \cdot 2$ k.m.), at the 0810 Transmissions.

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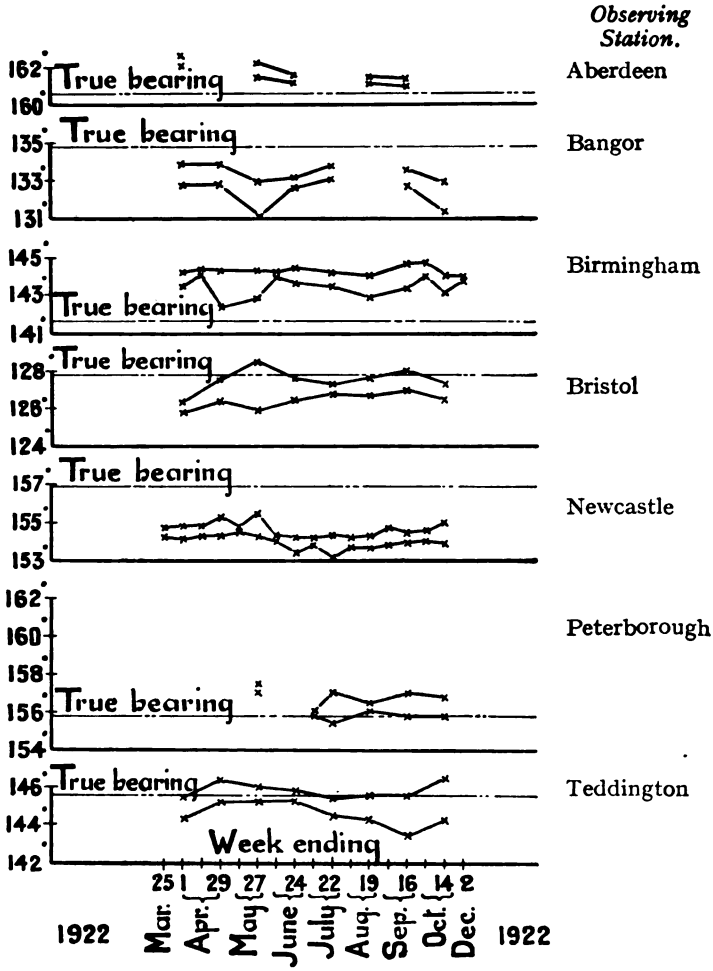

FIG. 3.—Graphs of Weekly Extreme Bearings of Paris (Damped Waves, $\lambda = 2{\cdot}6$ k.m.), at the 1130 Transmissions.

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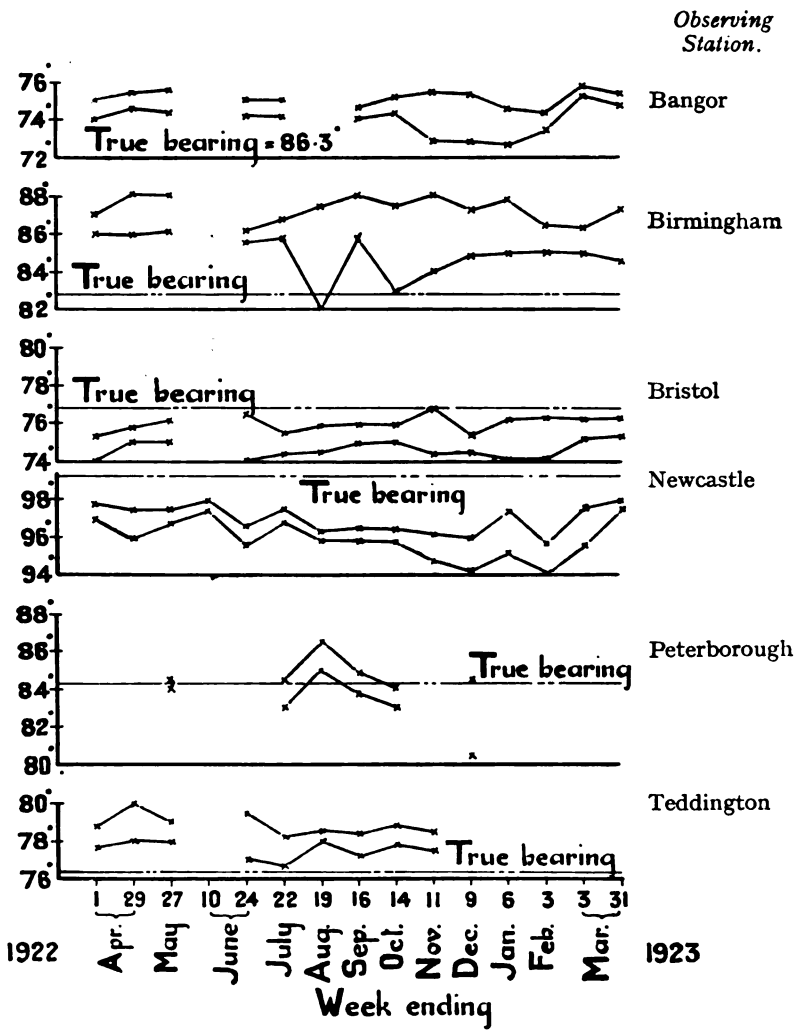

FIG. 4.—Graphs of Weekly Extreme Bearings of Nauen (Damped Waves, $\lambda = 3{\cdot}2$ k.m.), at the 1150 Transmissions.

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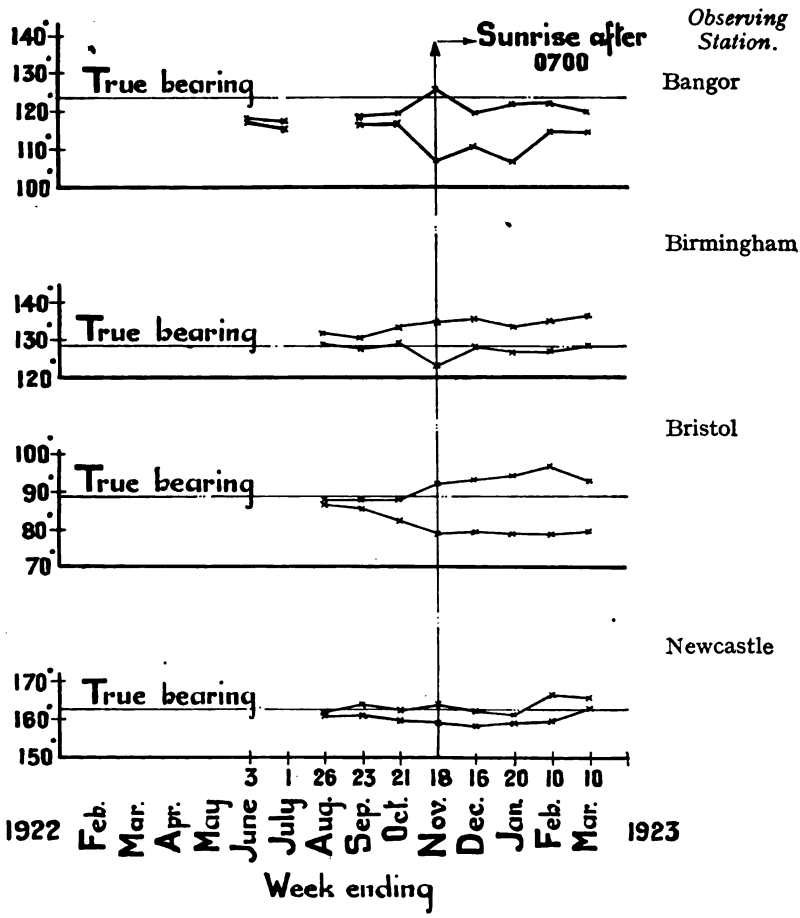

FIG. 5.—Graphs of Weekly Extreme Bearings of Air Ministry (Undamped Waves, $\lambda = 4 \cdot 1$ k.m.), at 0800 to 0930 Transmissions.

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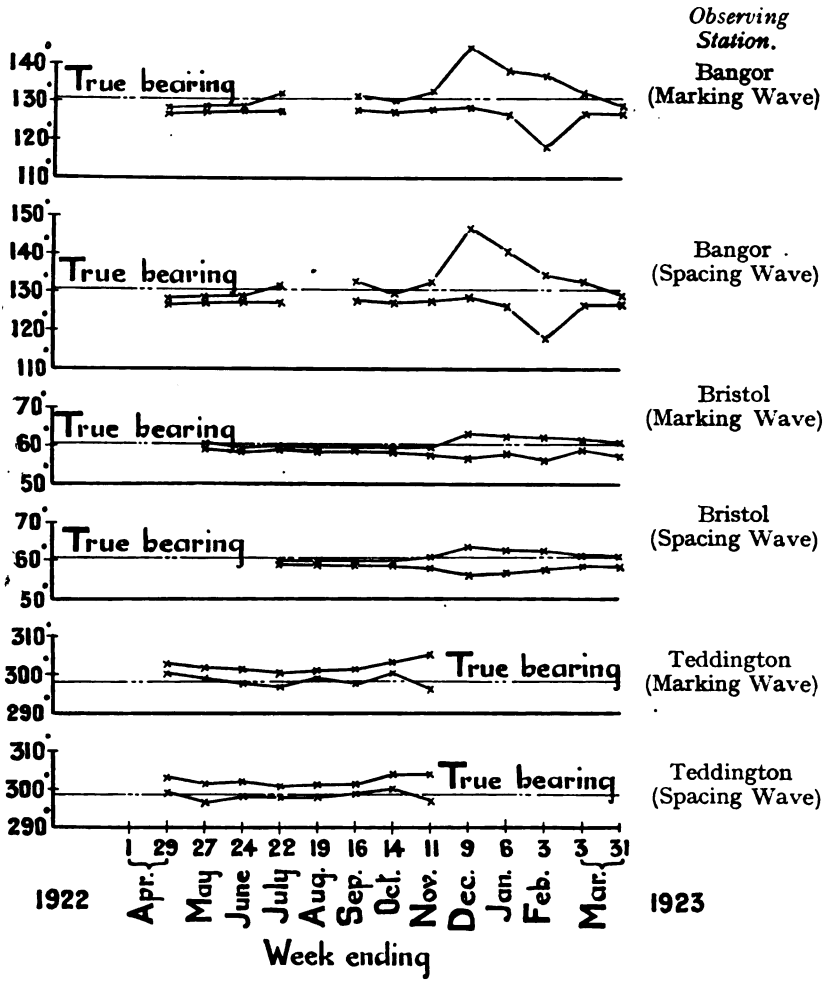

FIG. 6.—Graphs of Weekly Extreme Bearings of Leafield (Undamped Waves, $\lambda = 8{\cdot}7$ k.m.), at the 1200 Transmissions.

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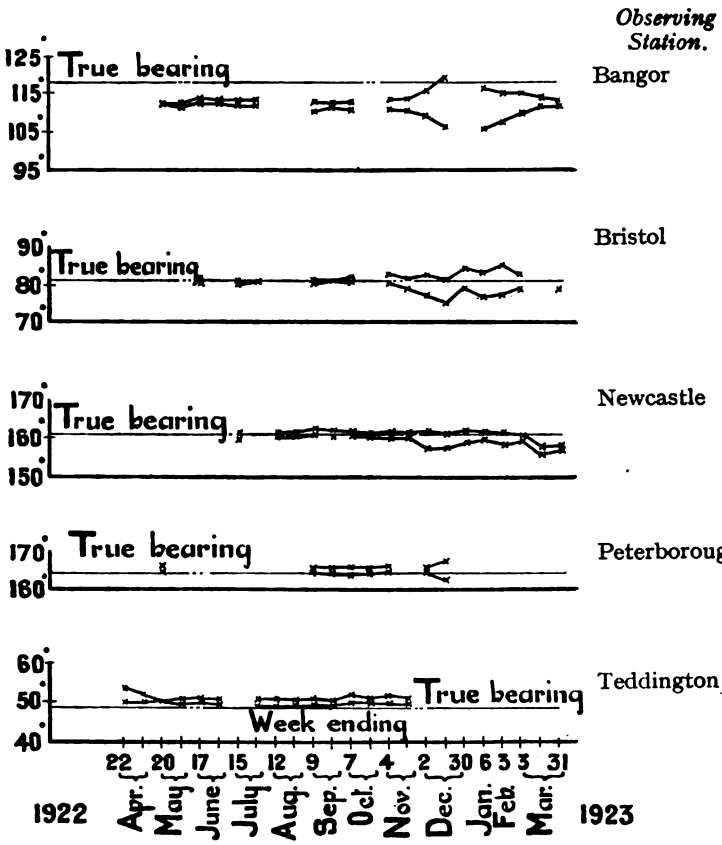

FIG. 7.—Graphs of Weekly Extreme Bearings of Ongar (Undamped Waves, $\lambda = 2{\cdot}9$ k.m.), at 1100 to 1230 Transmissions.

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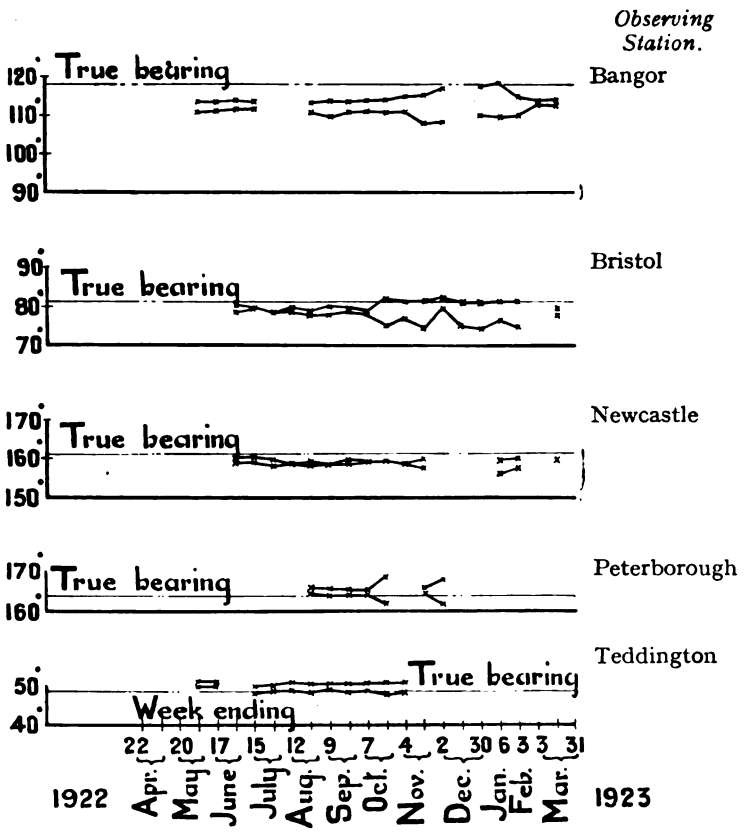

FIG. 8.—Graphs of Weekly Extreme Bearings of Ongar (Undamped Waves, $\lambda = 4{\cdot}4$ k.m.), at 1100 to 1230 Transmissions.

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Omitting the excessive variations noted during the winter months on the Air Ministry and Leafield stations, it will be seen from Figs. 5 and 6 that these two stations using undamped waves give variations of the same order as those of Paris, Nantes and Nauen using damped waves (Figs. 1–4). Figs. 7 and 8 represent the extreme bearings for two of the Ongar transmitting stations observed during the same periods as those for Leafield in Fig. 6. The increase in the variations observed during the winter months is seen to be similar to that of Leafield, although to a less degree It is interesting to observe that in the Ongar transmissions there is no obvious difference in the extent of the variations observed on the two wave-lengths.

(6) *Daily Variation Curves*

Figs. 9–12 show a graphic representation of the extreme bearings obtained from day to day for several transmitting and receiving stations. Figs. 9 and 11 well illustrate what appears to be the characteristic of the comparatively small day variations, viz., that these changes of 1° or 2° take place from day to day, and that over the space of half an hour's observation the variation is usually limited to a few tenths of a degree. As remarked in Part I of the report* there is no obvious similarity between the changes occurring at different receiving stations. It is to be noticed, however, that in practically every case the day-to-day variations are more marked during the winter than during the summer months. In Figs. 11 and 12 (plotted to five times the scale) many of the changes are seen to be of the same nature as the above, although often of a greater magnitude (10°–15°). In addition to these variations, however, it will be noticed that there are cases in which an appreciable variation takes place during the periods of observations. This occurrence is characteristic of the more general variations experienced at night, and whereas in the case of the Air Ministry's transmissions (Fig. 11) the observations plotted were all made within one hour of sunrise, in the case of Leafield (Fig. 12) sunrise occurred some four hours previously, this illustrating the persistence of night effect during the winter months as discussed in (4) above.

* See Bibliography (p. 107)—ref. 2, p. 56.

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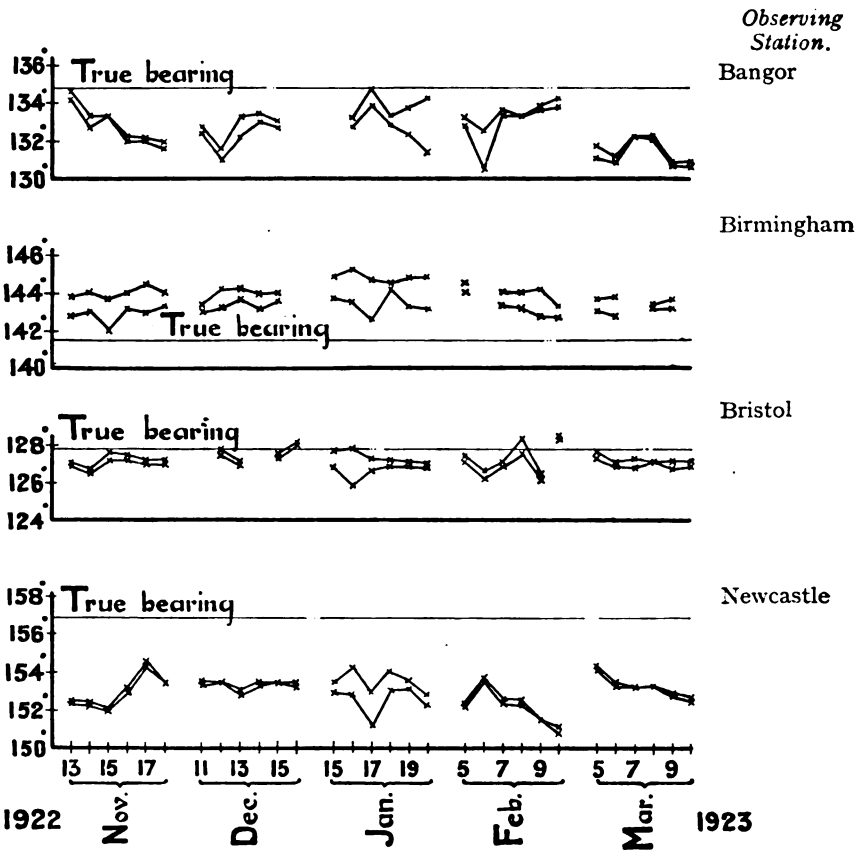

FIG. 9A.—Graphs of Daily Extreme Bearings of Paris (Damped Waves, $\lambda = 2{\cdot}6$ k.m.), at the 0920 Transmissions.

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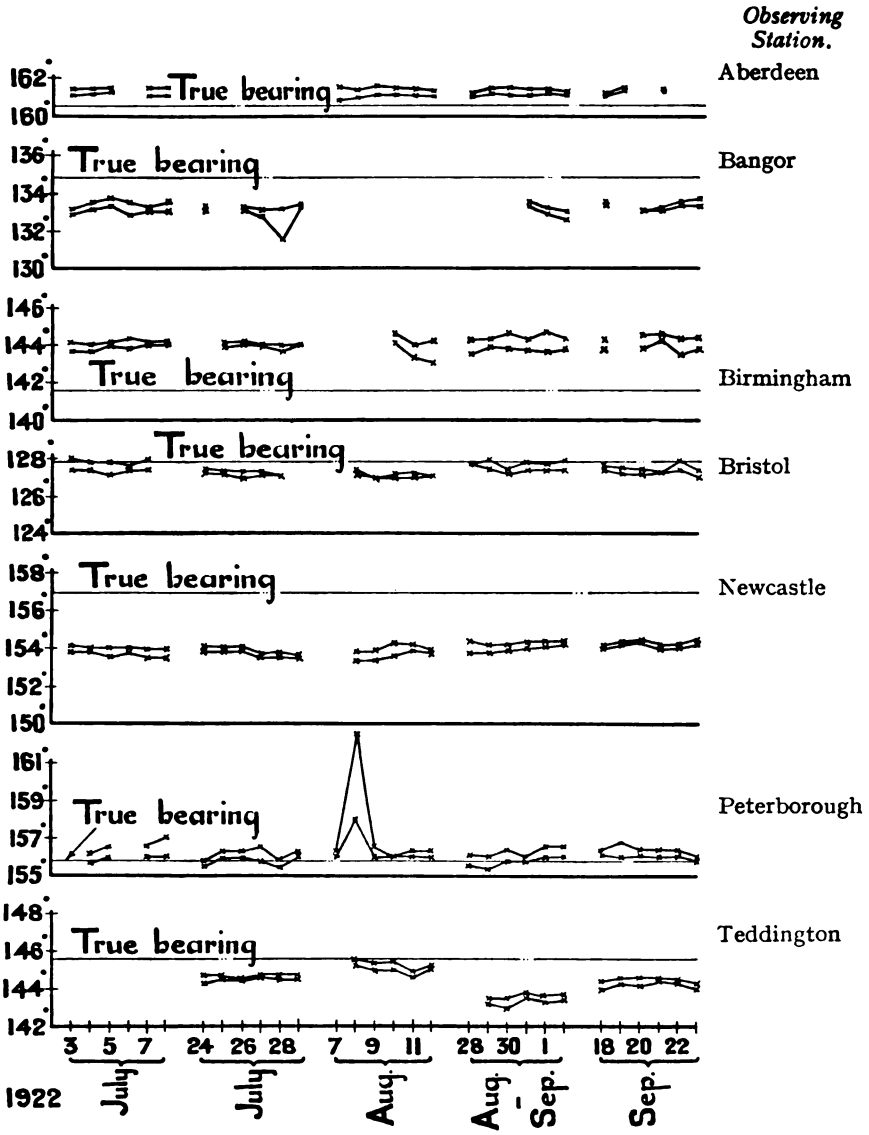

FIG. 9B.—Graphs of Daily Extreme Bearings of Paris (Damped Waves, $\lambda = 2{\cdot}6$ k.m.), at the 0920 Transmissions.

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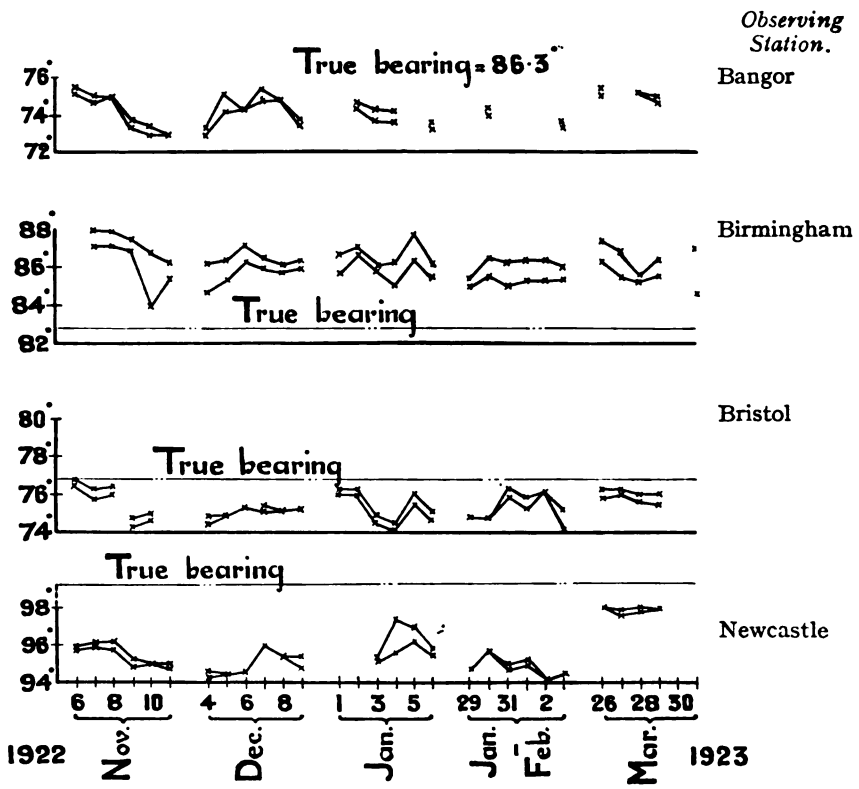

FIG. 10.—Graphs of Daily Extreme Bearings of Nauen (Damped Waves, $\lambda = 3{\cdot}2$ k.m.), at the 1150 Transmissions.

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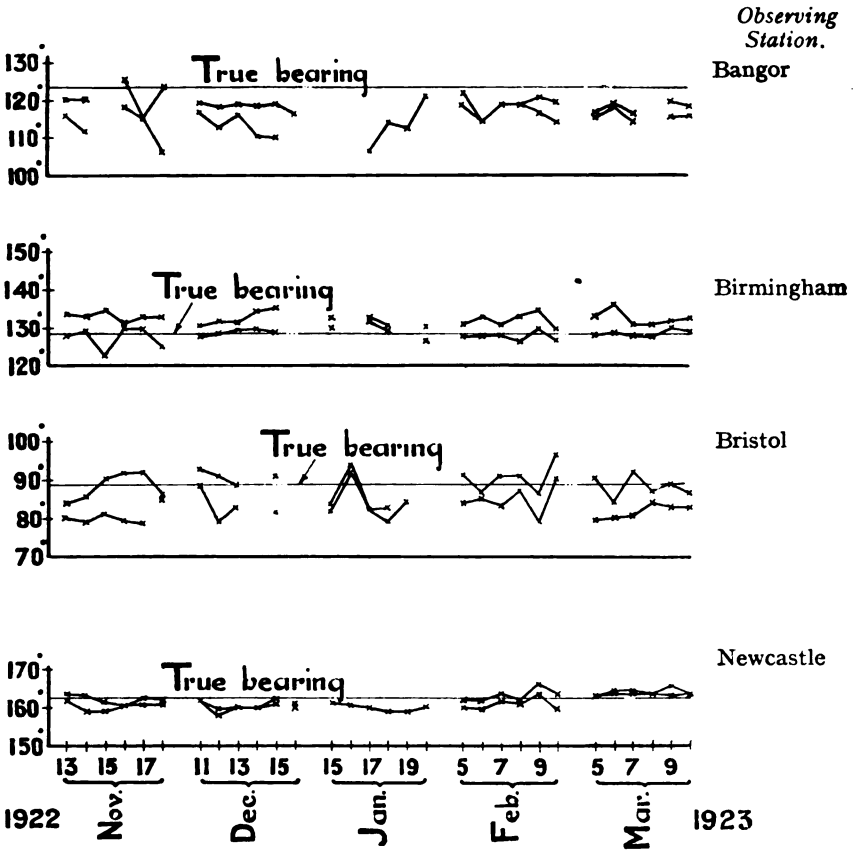

FIG. 11.—Graphs of Daily Extreme Bearings of Air Ministry (Undamped Waves, $\lambda = 4 \cdot 1$ k.m.), at 0800 to 0930 Transmissions.

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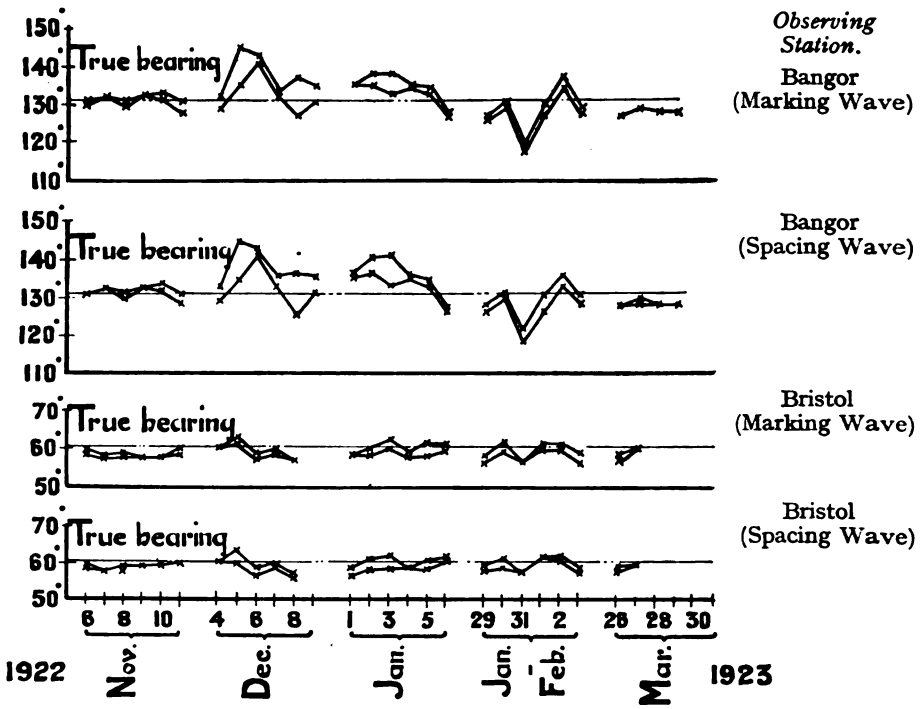

FIG. 12.—Graphs of Daily Extreme Bearings of Leafield (Undamped Waves, $\lambda = 8{\cdot}7$ k.m.), at the 1200 Transmissions.

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SECTION III.—DISCUSSION OF RESULTS—NIGHT OBSERVATIONS

(7) *Systematic error of the mean bearings at night*

The summary of the observations taken in the evening periods, as recorded in Tables 1 to 10, shows that there is practically no systematic error of the night variations. In the large majority of cases the difference between the day and night means is less than 2°, although in other cases it is nearly 5°. Where observations have been taken on two or more wave-lengths from one transmitting station it is usual for the systematic night error to be different for the two wave-lengths. Among the increased numbers of results now under discussion, there does not appear to be any confirmation of the relation observed in Part I of the report* between the true bearing of the station and the systematic error. Even for the two stations, Karlsborg and Poldhu, discussed last year from this point of view, the relation is not upheld. It is to be concluded, therefore, that in comparison with the large variations always experienced at night the systematic errors obtained are negligible, and that on the average the night errors are equally distributed on either side of the true bearings.

(8) *Magnitude of night variations*

Table No. 12 gives details of the two largest variations recorded at each receiving station over the period of observation under review for both damped and undamped wave working. The proportion of the readings which differ from the mean by more than 10° is also given in columns 5 and 7 of the table.

As was noticed last year,† Karlsborg and Moscow are still the most prominent spark transmitting stations giving rise to large variations at most of the observing stations; while among the C.W. stations brought under observation during this year Nauen most frequently gives the largest variation at any one receiver.

It is interesting to observe that the two largest variations recorded in the table—viz., Leafield to Peterborough and Nauen to Teddington—are over the very widely different ranges of transmission of 77 and 575 miles respectively. This adequately confirms the preliminary conclusion reached last year, that excessive variations are as likely to occur over short distances of the order of 100 miles chiefly overland as over longer distances of from 500 to 1,500 miles, of which an appreciable proportion is oversea in some instances.

* See Bibliography (p. 107)—ref. 2, p. 63.
† ditto ditto —ref. 2, p. 64.

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TABLE 12—*Showing the Two Largest Variations Recorded at each Observing Station for both Damped and Undamped Waves*

(1)	(2)	(3)	(4)	(5)	(6)	(7)
			"Spark."		"C.W."	
Observing Station.	Transmitting Station.	Wave Length.	Extreme Variation.	Percentage differing from mean by more than 10°.	Extreme Variation.	Percentage differing from mean by more than 10°.
		(km.)	(deg.)		(deg.)	
Aberdeen* ..	Karlsborg ..	2·5	32·3	15·1	—	—
	Karlsborg ..	4·2	7·5	0·0	—	—
	Karlsborg ..	3·9	—	—	34·3	2·5
	Nauen ..	4·7	—	—	7·0	0·0
Bangor ..	Coltano ..	4·2	44·8	11·4	—	—
	Karlsborg ..	2·5	34·4	11·7	—	—
	Leafield ..	8·8	—	—	65·7	10·5
	Ongar.. ..	2·9	—	—	62·1	21·9
Belfast* ..	Karlsborg ..	4·2	12·0	0·0	—	—
	Karlsborg ..	2·5	11·0	0·0	—	—
	Nauen ..	4·7	—	—	13·5	0·0
	Clifden ..	5·8	—	—	11·5	0·0
Birmingham	Karlsborg ..	2·5	47·5	12·6	—	—
	Moscow ..	4·8	17·3	0·5	—	—
	Konigswusterhausen	5·2	—	—	23·0	5·5
	Ongar.. ..	3·8	—	—	21·7	0·9
Bristol ..	Karlsborg ..	2·5	41·0	7·1	—	—
	Moscow ..	4·8	20·0	0·9	—	—
	Nauen ..	4·7	—	—	67·2	6·2
	Ongar.. ..	2·9	—	—	63·0	32·5
Cambridge* ..	Karlsborg ..	2·5	59·0	13·3	—	—
	Poldhu ..	2·8	27·0	9·0	—	—
	Nauen ..	4·7	—	—	14·6	12·5
	Ongar.. ..	2·9	—	—	10·0	0·0
Newcastle ..	Karlsborg ..	2·5	57·5	20·2	—	—
	Sofia	3·2	48·0	3·7	—	—
	Nauen ..	4·7	—	—	78·2	5·9
	Ongar.. ..	2·9	—	—	59·5	5·9
Peterborough*	Karlsborg ..	2·5	61·0	20·1	—	—
	Moscow ..	4·8	27·3	3·9	—	—
	Leafield ..	8·6	—	—	99·5	42·6
	Nauen ..	4·7	—	—	50·0	15·1
Teddington* ..	Karlsborg ..	2·5	54·8	11·2	—	—
	Poldhu ..	2·8	19·5	1·5	—	—
	Nauen ..	4·7	—	—	89·0	7·4
	Konigswusterhausen	5·2	—	—	45·0	14·6

* Station not observing for whole year.

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Furthermore the largest variations recorded are of the same order for the various wave-lengths included in Table 12. Finally, it is to be noted that the spark transmissions give rise to variations of a similar order to those observed on C.W. transmissions; and particularly is the percentage of differences of more than 10° from the mean of the same order for both types of transmission. Further discussion of these matters will be given later in this report. (*See* p. 79).*

(9) *Relation of variations with the direction of transmission*

Figs. 17 and 18 in Part I of the report† appeared to indicate a definite relationship between the extent of the night variations and the direction of transmission. Of the further results now being discussed it is probably significant that in Table 12 above, the stations giving rise to the largest variations mostly lie in a north-easterly or easterly direction from the receiver, in agreement with previous conclusions. Referring more generally to this year's readings, a graphical representation of the extreme amplitude of observed bearings plotted against the true bearing is given in Figs. 13 (A and B). The first diagram is confined to those transmitting stations situated in the British Isles, while Fig. 13B refers only to stations outside the British Isles. To reduce as far as possible the introduction of spurious effects, the results are only plotted for the stations upon whose transmissions a representative number of observations (not less than 100) have been taken and with an adequate distribution over the year of working.

The scattering of the points plotted in the two diagrams makes it practically impossible to draw any well-defined curve, and as it was thought that the extreme variation might in some cases be exaggerated by occasional freak conditions and would not be representative of the average behaviour, the results have been replotted in Figs. 14 (A and B) in the form of the percentage of observations which differ from the mean by more than 5°. While again no definite curve can be drawn, there is a marked concentration of the largest variations to the E.W. direction of transmission with a corresponding minimum in the N.S. direction. In a separate series of experiments [3] carried out independently of the present investigation it has been shown that the shape and dimensions of the transmitting aerial have no measurable effect upon the magnitude and frequency of the variations in observed bearings, so that these are not a characteristic of the transmitting station. There are, however, other factors such as geographical features, which might influence the results obtained upon different transmitting stations.

In spite of the widely varying conditions prevailing in the different cases, there is a definite suggestion among the results obtained that when the direction of transmission is approximately on the North and South line, the variations in bearings observed,

* This subject is further dealt with in Part III of this Report to be published shortly.

† See Bibliography (p. 107)—ref. 2, p. 65.

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although still very appreciable, are on the whole less serious than those observed on transmissions in the East and West direction. The matter can probably only be settled definitely by an elaborate investigation employing a transmitting station situated in very uniform country and a number of similar direction-finding

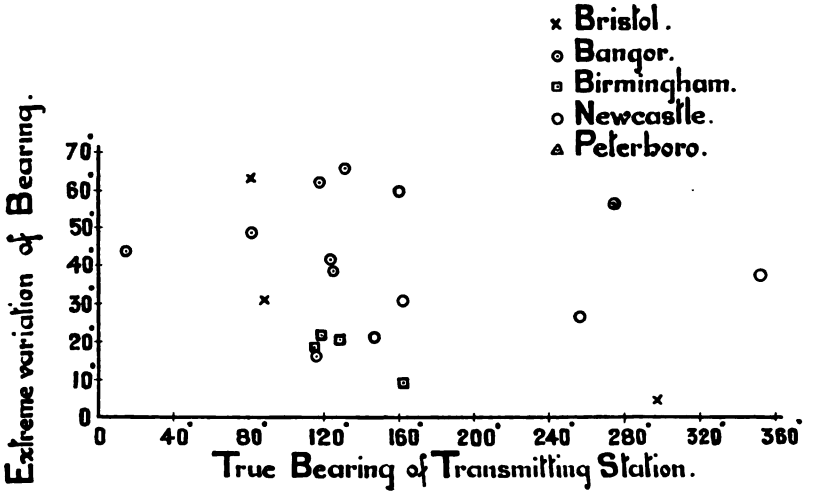

FIG. 13A.—Showing Relation of Extent of Variations to True Bearing for Transmitting Stations in the British Isles.

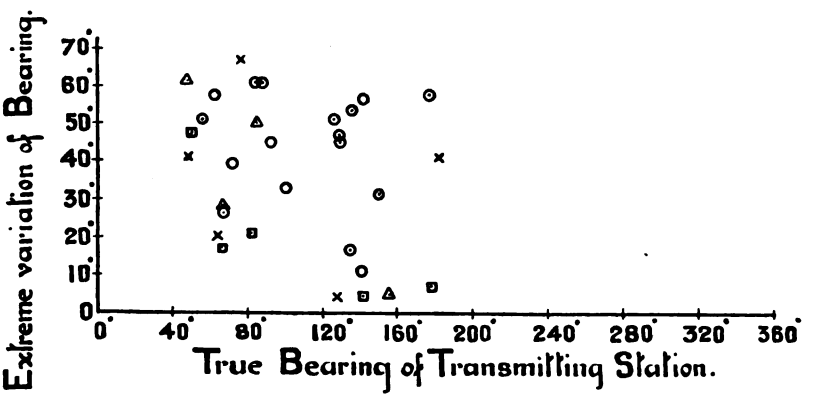

FIG. 13B.—Showing Relation of Extent of Variations to True Bearing for Transmitting Stations outside the British Isles.

stations located at equal distances on identical sites, taking simultaneous observations upon the transmissions from the centre station.

(10) *Dependence of variations upon wave-length*

As previously deduced, the collection of results now under discussion does not show any appreciable relation between wave-length and extent of variation over the range of wave-lengths

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2,000 to 9,000 metres. Many examples may be noted in the preceding tables of excessive night variations in bearings on wave-lengths near the upper and lower limits of the range employed. This conclusion, applying to a number of observations taken over a period, is to be distinguished from the statement previously

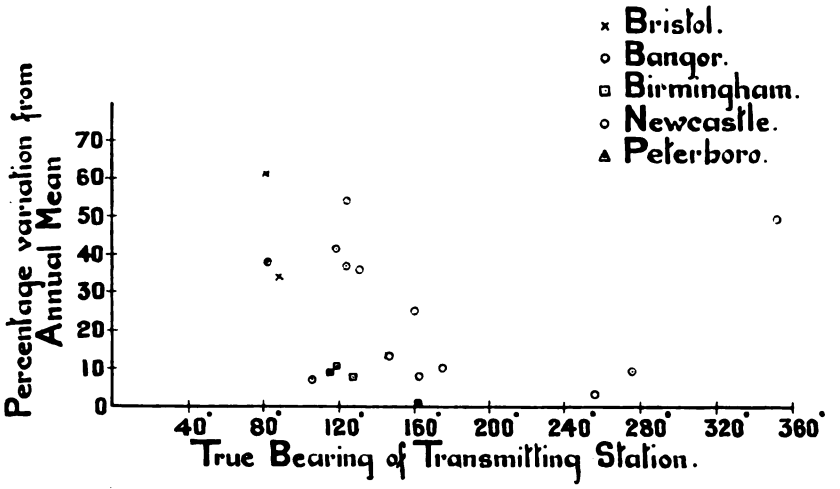

FIG. 14A.—Showing Percentage Variation against True Bearing for Transmitting Stations in the British Isles.

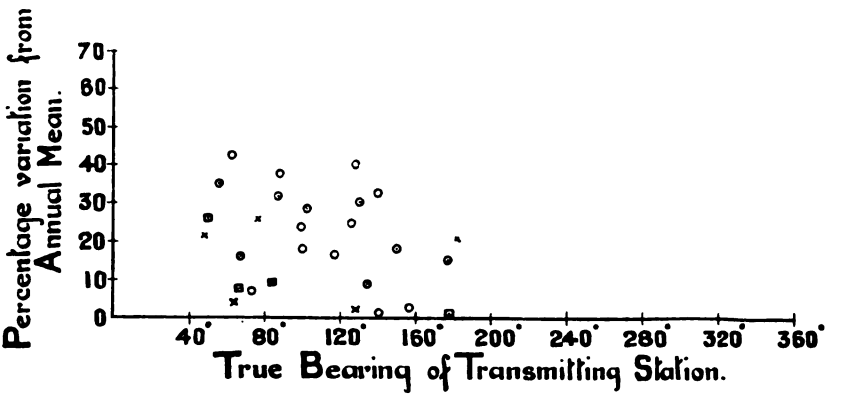

FIG. 14B.—Showing Percentage Variation against True Bearing for Transmitting Stations outside the British Isles.

made as to the change in apparent bearing taking place when the wave-length of transmission is changed *instantaneously*. Excellent examples of this last occurrence have been obtained among the present results in the case of arc transmitting stations, and in particular Leafield is especially prominent. These stations usually employ a marking and spacing wave for signalling purposes, the difference in lengths of these waves being of the order of 1 per cent. of the wave-length. It was constantly noticed at all

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receiving stations in the case of Leafield, that when the observed bearing on the marking wave was in error the bearing taken on the spacing wave immediately afterwards was also in error but generally by a different amount. Graphical illustrations of this effect have been given in an earlier report.[4] Over a period of half an hour's observations, the bearings on the two waves would swing to and from each other, occasionally crossing, while at other times the two waves gave bearings on opposite sides of the true bearing. These differences, however, are only temporary, and the amplitudes of variation and the systematic error of a number of observations remain independent of the wave-length.

(11) *Weekly variation curves*

A representative selection of the graphs obtained by plotting the weekly extreme bearings for different transmitting and receiving stations is given in Figs. 15–20. To enable comparisons to be made, several of the transmitting stations selected are the same as those noted in Figs. 1–8. Fig. 15 illustrates the results obtained on the evening transmissions from the Paris "spark" station. Although it is noticeable that the variations are greater when the observations are taken after sunset, the extreme variations obtained even at night are comparatively small—rarely more than 10°. This is in perfect agreement with the results obtained during the preceding year*, and remains at present without explanation. The small variation would not appear to be entirely due to the direction of transmission, for larger variations are obtained on the undamped wave transmissions from other stations in the neighbourhood of Paris (*see* Tables 1 and 10). In one case, Paris (UFP) observed at Teddington, the wave-length is very similar to that employed on the damped wave transmissions from Paris (FL), so that it is not a question of change of wave-length. The other reasons formerly suspected were based on either the configuration of the transmitting aerial, or the change from damped to undamped waves. Experiments carried out with short waves (450 metres) and over distances of about 100 miles [3] have shown that the night effects experienced on direction-finders are independent of the shape of the transmitting aerial. The question of the effect of wave-damping is discussed in a later section (*see* p. 79), from which it will be seen that the damping is unlikely to be the cause.

Fig. 16 illustrates the increase in the variations of bearings observed on the Air Ministry station after sunset in a similar manner to those taken about sunrise and plotted in Fig. 5. The small variation experienced at Teddington is evidently due to the small range of transmission, 17 miles (*see* Table 17 and p. 78).

The observations plotted in Figs. 17–20 represent the records taken on five different transmitting stations during the same periods of working, centred round 2000 G.M.T. Fig. 17 shows

* See Bibliography (p. 107)—ref. 2, p. 72, Fig. 24.

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the very large and erratic variations recorded on Leafield's transmissions at various observing stations. The extreme bearings for the marking and spacing waves have the same general characteristics, and it is interesting to note that as the distance of transmission is increased from 51 miles at Bristol to 60 miles at Teddington and 77 miles at Peterborough, the extent of the variations increases considerably, but that for the greater distance to 144 miles at Bangor the variations appear to have decreased a little.

Similar remarks apply to the variations plotted for Ongar on Figs. 18 and 19. The variations encountered at Teddington and Peterborough at distances of 30 and 64 miles respectively are in general much less than at the other stations, each of which is more than 100 miles from Ongar. Having due regard to this distance relation, and excepting the abnormal effects experienced at Peterborough on Leafield, there is no obvious relation between the wave-length and the extent of variation observed in Figs. 17–19. Comparing these with the records plotted in Fig. 20 for Karlsborg, it appears that for much greater distances of transmission up to 800 miles the extent of the variations is comparatively unaltered, thus confirming the deduction drawn in (8) above (*see* p. 49).

A noticeable distinction between Figs. 17–19 and Fig. 20 is that whereas the night variations on Karlsborg do not appear to commence until after sunset at the receiver—*i.e.*, until darkness prevails over the whole path of transmission—in the case of Leafield and Ongar the variations have commenced while the sunset boundary is passing over the path of transmission.

Another point to be observed as common to all the cases is that when darkness has once set in there is afterwards no obvious alteration in the extent of the variations, these being quite violent in December to February in the cases illustrated, when sunset occurred three to four hours before the period of observation.

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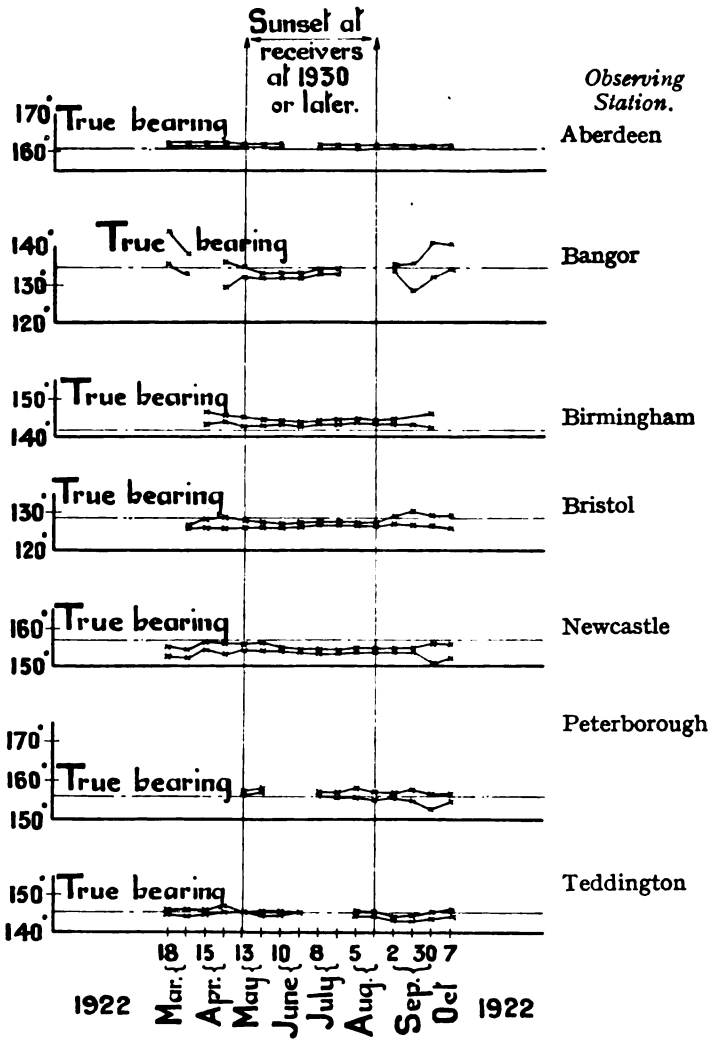

FIG. 15.—Graphs of Weekly Extreme Bearings of Paris (Damped Waves, $\lambda = 2{\cdot}6$ k.m.), at the 1920 Transmissions.

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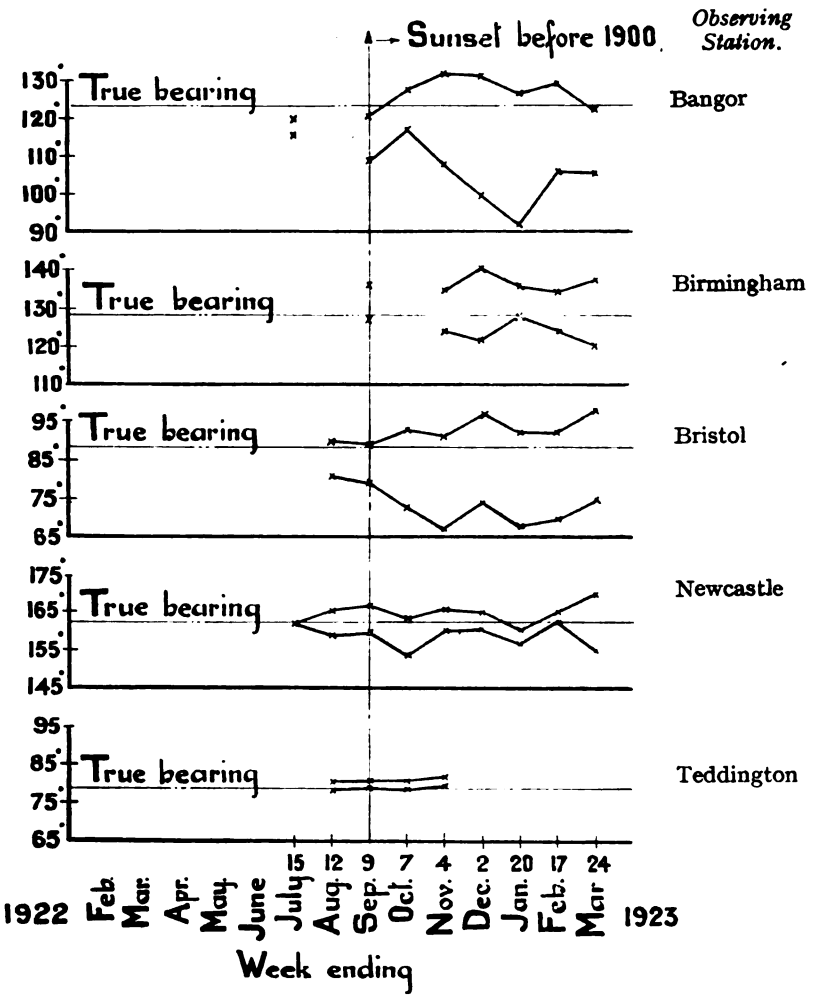

FIG. 16.—Graphs of Weekly Extreme Bearings of Air Ministry (Undamped Waves, $\lambda = 4 \cdot 1$ k.m.), at 1900 to 2030 Transmissions.

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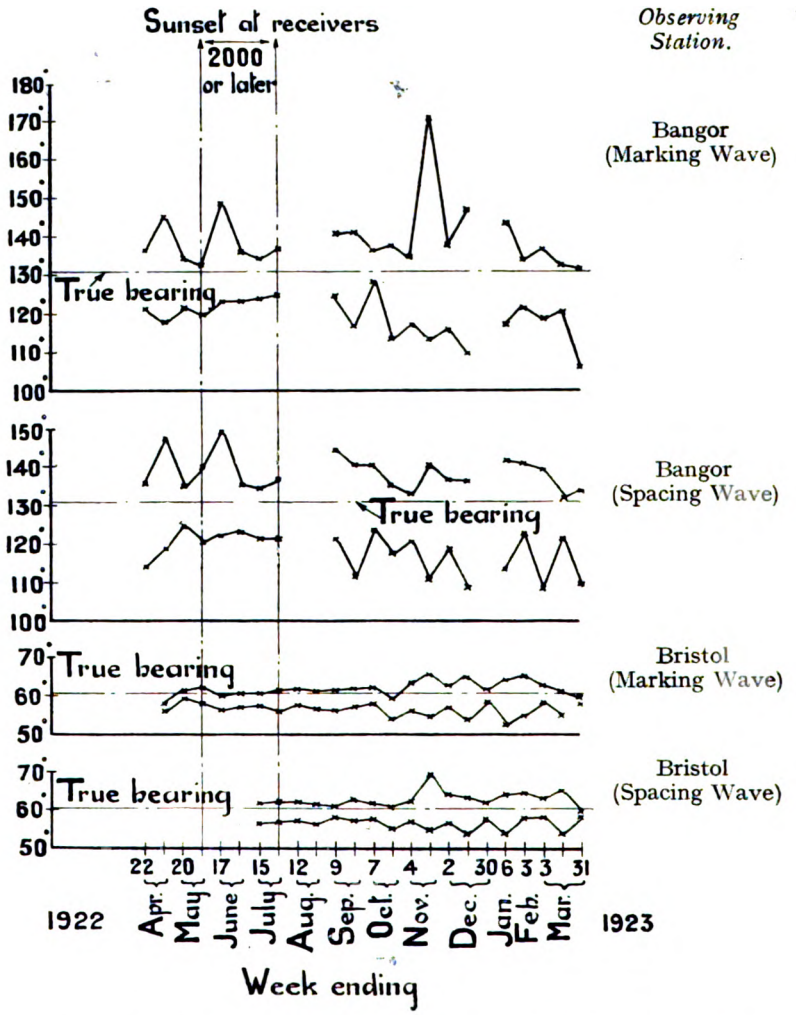

FIG. 17A.—Graphs of Weekly Extreme Bearings of Leafield (Undamped Waves, $\lambda = 8{\cdot}7$ k.m.), at the 2000 Transmissions.

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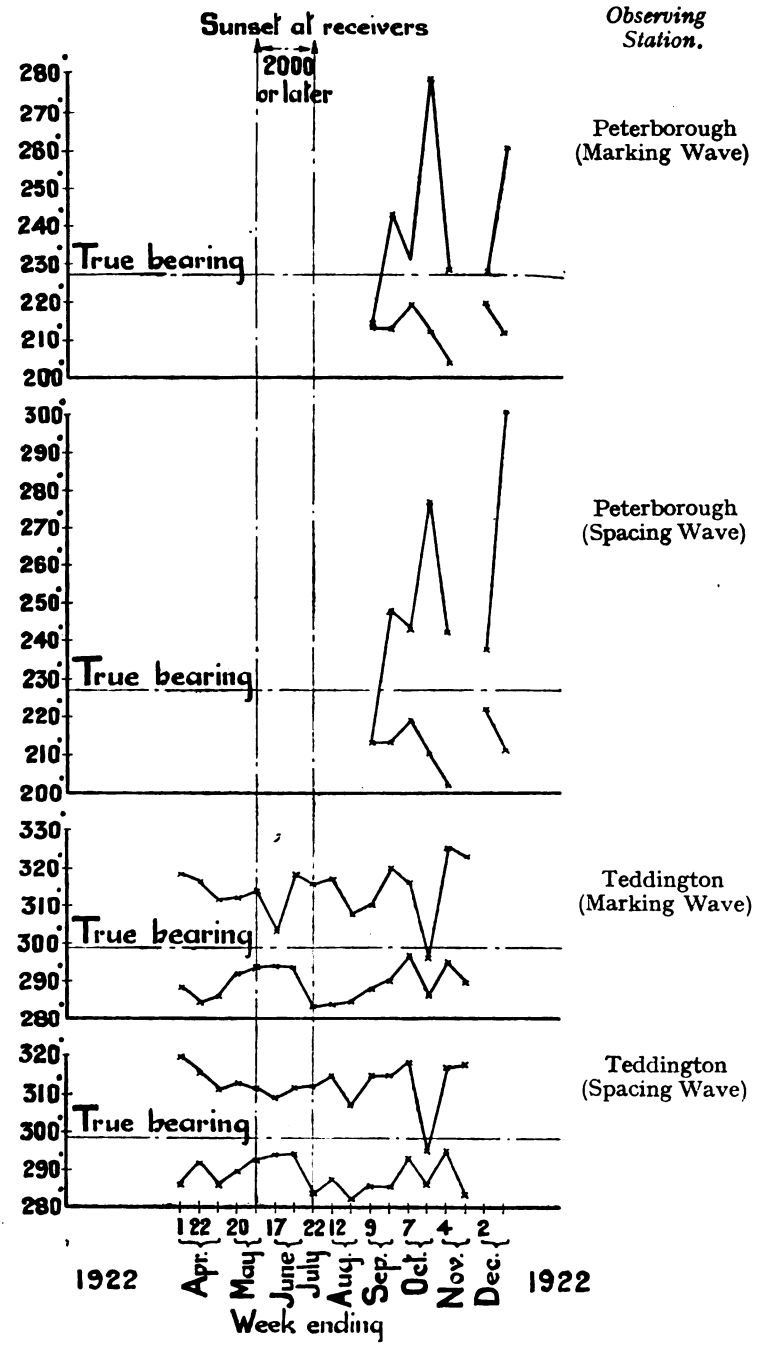

FIG. 17B.—Graphs of Weekly Extreme Bearings of Leafield (Undamped Waves, $\lambda = 8{\cdot}7$ k.m.) at the 2000 Transmissions.

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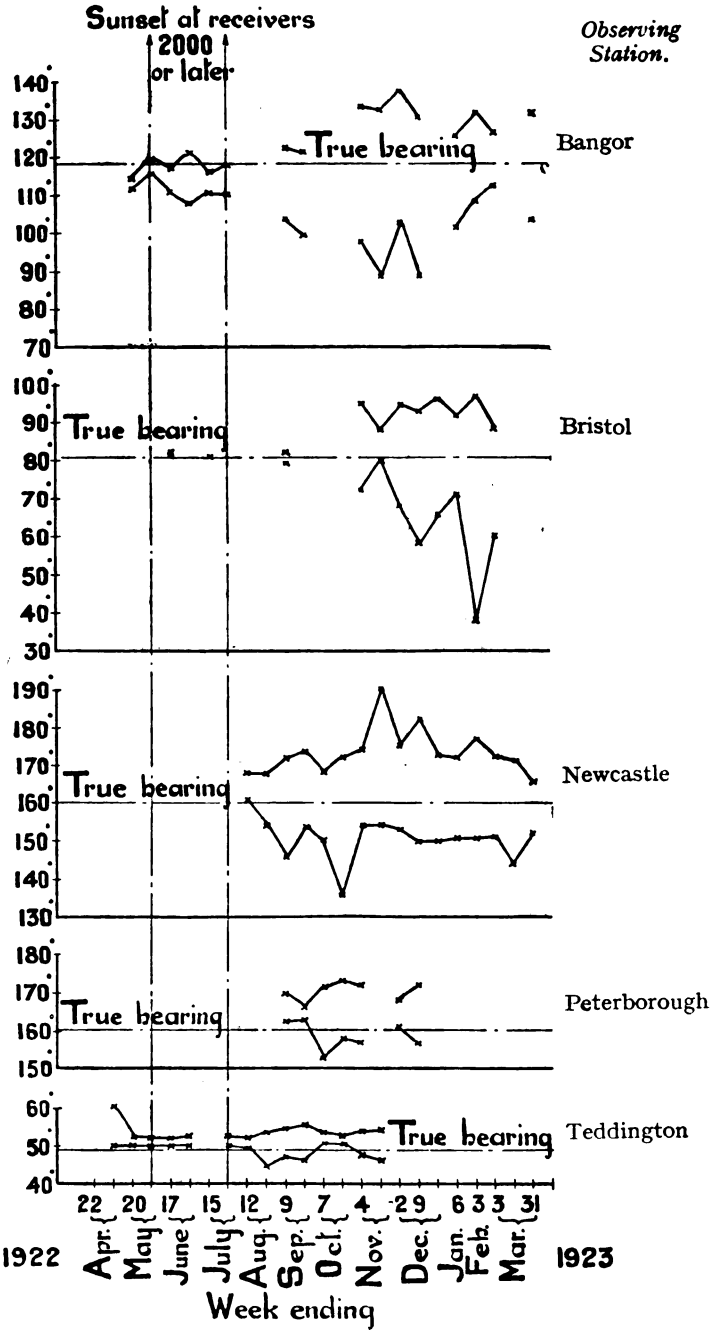

FIG. 18.—Graphs of Weekly Extreme Bearings of Ongar (Undamped Waves, $\lambda = 2{\cdot}9$ k.m.), at 1800 to 2200 Transmissions.

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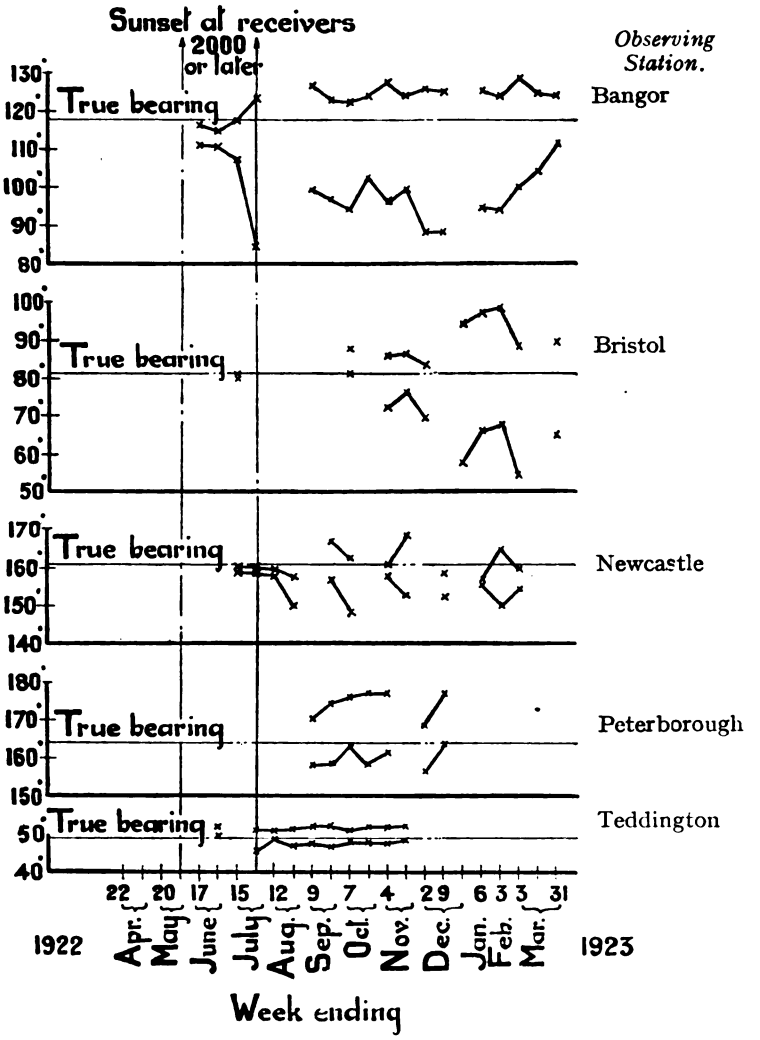

FIG. 19.—Graphs of Weekly Extreme Bearings of Ongar (Undamped Waves, $\lambda = 4{\cdot}4$ k.m.) at 1800 to 2200 Transmissions.

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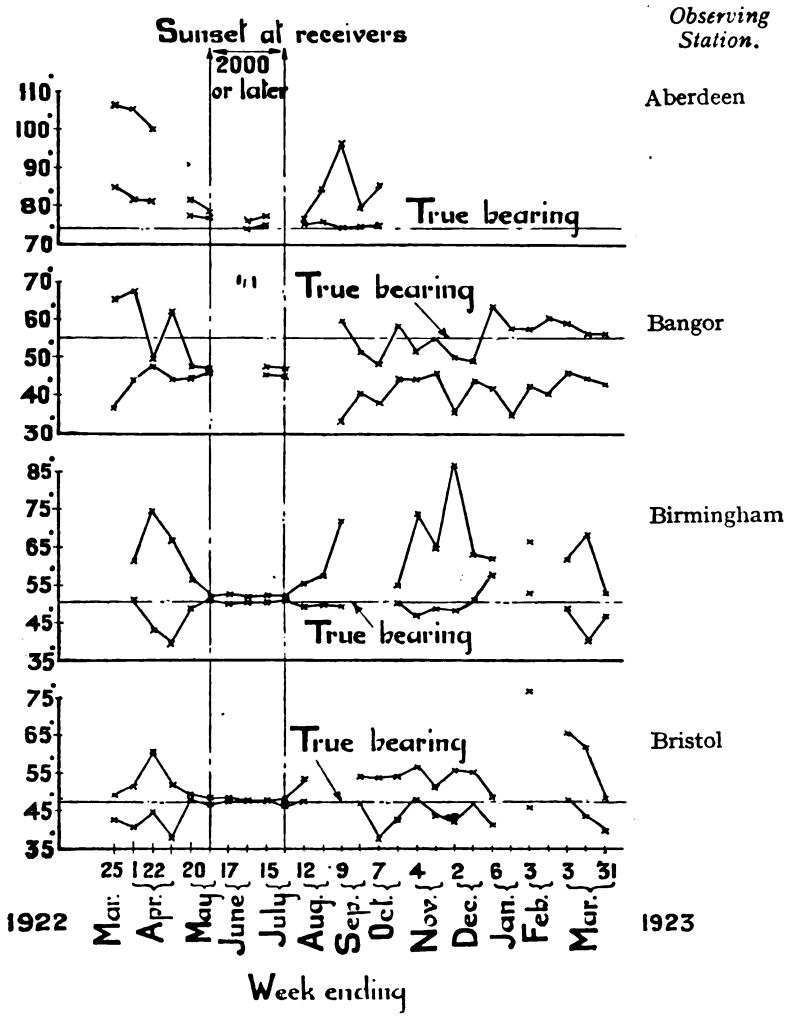

FIG. 20A.—Graphs of Weekly Extreme Bearings of Karlsborg (Damped Waves, $\lambda = 2 \cdot 5$ k.m.), at the 2000 Transmissions.

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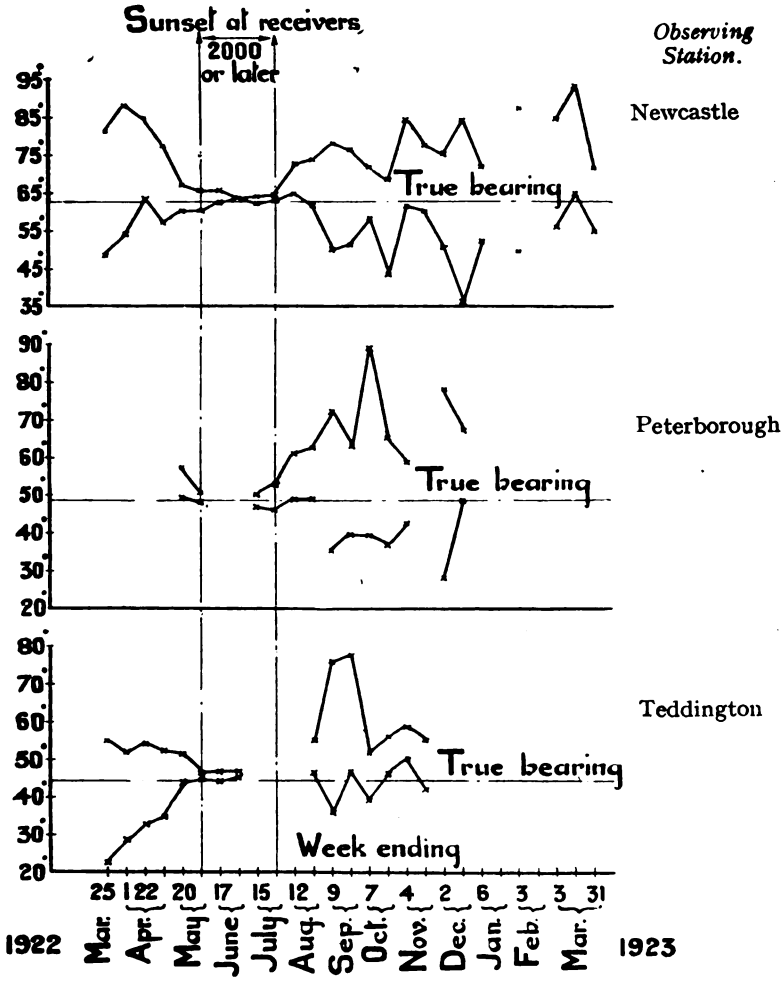

FIG. 20B.—Graphs of Weekly Extreme Bearings of Karlsborg (Damped Waves, $\lambda = 2 \cdot 5$ k.m.), at the 2000 Transmissions.

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(12) *Percentage errors of bearings*

To assist in the analysis of the large numbers of results dealt with, the percentage of observed bearings which differ from the annual mean by certain fixed amounts have been worked out for each receiving station, and these are given in Tables 13–16 for the four stations which were in continuous operation during the whole of the observation year 1922–23.

These tables will be referred to in the succeeding sections, but one or two outstanding points in them may be mentioned here. During the day-time an appreciable number of the observed bearings differ from the mean by more than 2°, but a comparatively small number are more than 5° in error. Even including the abnormal results discussed above in (4) and Table 11, there are few cases in which more than 10 per cent. of the day readings exceed the error limit of 5°. Of the night readings, however, this proportion may be anything up to 60 per cent., and quite an appreciable fraction of these are more than 10° in error. Considering the large variations which have been referred to in Table 12, it is interesting to note that these are of comparatively rare occurrence, since the percentage of bearings which differ from the mean by more than 20° is very small. As has been repeatedly observed in both this and Part I of the report, the proportion of serious errors is much greater at Bangor than elsewhere, evidently due to the mountainous district in which this station was situated.

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TABLE 13.—*Showing Percentage Variations of Bearings from the Annual Mean at Bangor, 1922–23*

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.						
					Over 2°.		Over 5°.		Over 10°.		Over 20°.
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Night.
	km.										
Aberdeen	C.W. 3·3	0830 1700	93	67	3·2	38·8	0·0	20·9	0·0	2·9	1·5
Aberdeen	C.W. 3·3	2100	—	35	—	77·2	—	42·9	—	14·3	0·0
Air Ministry	C.W. 4·1	I.	176	131	19·3	59·5	5·1	37·4	1·1	13·7	3·1
Aranjuez	C.W. 3·7	I.	671	586	9·4	66·4	1·0	37·0	0·0	15·0	1·9
Berne	C.W. 3·4	I.	774	323	18·1	80·0	0·8	50·2	0·0	24·8	4·3
Budapest	C.W. 4·3	I.	444	281	5·6	62·0	0·0	27·7	0·0	12·5	0·7
Chelmsford	C.W. 3·8	I.	132	103	—	10·7	0·0	6·8	0·0	0·0	0·0
Cleethorpes	C.W. 4·3	0800	73	—	35·6	—	13·7	—	2·7	—	—

I. = Irregular transmission.

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TABLE 13.—*Showing Percentage Variations of Bearings from the Annual Mean at Bangor*, 1922–23—continued

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations		Percentage Variations from Annual Mean.						
					Over 2°.		Over 5°.		Over 10°.		Over 20°.
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Night.
	km.										
Cleethorpes	C.W. 4·3	I.	51	115	15·7	75·6	2·0	38·2	0·0	17·4	1·7
Clifden	S. 5·8	0950	60	—	0·0	—	0·0	—	0·0	—	—
Clifden	C.W. 5·8	I.	344	469	0·0	29·7	0·0	9·6	0·0	4·1	3·8
Coltano	S. 4·2	I.	104	140	26·9	82·1	1·9	30·7	0·0	11·4	1·9
Horsea	C.W. 5·0	I.	69	48	17·4	58·3	2·9	31·2	0·0	4·2	0·0
Karlsborg	S. 2·5	1215	32	257	0·0	70·8	0·0	28·4	0·0	11·7	0·0
Karlsborg	S. 4·2	2000 I.	42	29	0·0	86·2	0·0	20·7	0·0	0·0	0·0
Karlsborg	C.W. 3·9	I.	540	291	7·6	34·4	1·3	19·2	0·0	7·2	1·0
Karlsborg	C.W. 4·3	I.	260	191	30·4	67·0	8·9	35·1	2·7	8·4	0·0

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Konigswusterhausen ..	C.W. 5·2	I.	1101	340	13·9	60·9	0·1	37·7	0·0	17·9	3·8
Leafield (M)	C.W. 8·8	1200 2000	277	552	33·9	69·0	10·1	35·2	2·9	10·5	0·5
Leafield (S)	C.W. 8·7	1200 2000	277	550	34·3	68·0	9·4	35·8	3·6	11·1	0·4
Lyngby (M)	C.W. 3·7	I.	45	69	20·0	92·8	0·0	50·7	0·0	17·4	0·0
Lyngby (S)	C.W. 3·6	I.	53	64	20·8	89·1	1·9	61·0	0·0	15·6	1·6
Malta	C.W. 4·2	I.	110	—	2·7	—	0·0	—	0·0	—	—
Moscow	S. 4·8	I.	121	361	0·0	53·2	0·0	16·3	0·0	3·9	0·0
Nantes	S. 2·5	0800 2100	18	48	22·2	12·5	0·0	0·0	0·0	0·0	0·0
Nantes	S. 4·2	0810 2130	51	41	0·0	9·7	0·0	0·0	0·0	0·0	0·0
Nantes	S. 2·5	1230	70	—	8·6	—	0·0	—	0·0	—	—
Nauen	S. 3·2	1150	158	—	0·0	—	0·0	—	0·0	—	—
Nauen	C.W. 4·7	I.	752	902	17·6	60·0	3·3	32·0	0·5	10·0	2·1
Nauen	C.W. 6·3	I.	472	756	9·3	58·0	1·1	19·9	0·0	5·0	0·3
Northolt (M)	C.W. 7·0	I.	171	186	18·7	75·8	2·3	49·5	0·0	14·5	1·6
Northolt (S)	C.W. 6·9	I.	171	186	19·3	79·6	2·3	54·3	0·0	12·4	0·5
Ongar	C.W. 2·9	I.	861	563	22·4	67·4	4·7	41·6	0·2	21·9	1·8

I. = Irregular transmission.

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TABLE 13.—*Showing Percentage Variations of Bearings from the Annual Mean at Bangor*, 1922–23—continued.

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.						
					Over 2°.		Over 5°.		Over 10°.		Over 20°.
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Night.
	km.										
Ongar	C.W. 3·8	I.	973	461	17·7	59·6	4·0	37·3	0·2	12·1	0·2
Ongar	C.W. 4·4	I.	847	1057	15·1	66·8	1·9	40·0	0·1	14·3	0·4
Paris	S. 2·6	0815	137	—	0·0	—	0·0	—	0·0	—	—
Paris	S. 2·6	0920 1920	895	108	1·8	34·2	0·0	9·3	0·0	0·0	0·0
Paris	S. 2·6	1130	135	—	0·0	—	0·0	—	0·0	—	—
Paris	S. 3·2	1200	74	—	0·0	—	0·0	—	0·0	—	—
Paris (M)	C.W. 7·6	I.	294	237	23·1	71·7	1·4	53·6	0·0	31·6	6·7
Paris (S)	C.W. 7·5	I.	294	231	26·2	67·0	0·7	45·5	0·0	22·5	1·3
Pembroke	C.W. 4·8	I.	23	48	0·0	35·4	0·0	12·5	0·0	0·0	0·0

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Poldhu	S. 2·8	0950 2150	14	10	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Poldhu	S. 2·8	I.	12	41	0·0	26·8	0·0	4·9	0·0	2·4	0·0
Rome (M)	C.W. 5·4	I.	79	343	15·2	75·0	0·0	39·1	0·0	17·5	2·0
Rome (S)	C.W. 5·3	I.	79	344	17·7	74·2	2·5	40·4	1·3	15·4	1·7
Stonehaven	C.W. 4·5	I.	673	552	15·9	57·7	2·8	32·8	0·1	11·4	0·5
Stonehaven	C.W. 5·5	I.	300	—	1·7	—	0·0	—	0·0	—	—
Tours (M)	C.W. 6·8	I.	238	249	7·6	54·2	0·0	18·5	0·0	2·4	0·0
Tours (S)	C.W. 6·6	I.	238	252	13·4	42·9	1·7	14·3	0·0	1·2	0·0
Whitehall	C.W. 3·3	1700	—	27	—	33·3	—	14·8	—	3·7	0·0
Whitehall	C.W. 3·3	2100	—	25	—	88·0	—	44·0	—	16·0	0·0

I. = Irregular transmission.

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TABLE 14.—*Showing Percentage Variations of Bearings from the Annual Mean at Birmingham, 1922–23*

(1)	(2)	(3)	(4)		(5)		(6)		(7)	(8)
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.					
					Over 2°.		Over 5°.		Over 10°.	Over 20°.
			Day.	Night.	Day.	Night.	Day.	Night.	Night.	Night.
	km.									
Air Ministry	C.W. 4·1	I.	542	382	15·5	31·6	0·9	8·3	0·0	0·0
Chelmsford	C.W. 3·8	I.	198	152	7·0	38·5	0·0	9·2	0·0	0·0
Clifden	S. 5·8	0950	71	—	0·0	—	0·0	—	—	—
Coltano	S. 4·2	I.	71	94	9·9	19·1	0·0	0·0	0·0	0·0
Horsea	C.W. 5·0	I.	381	323	1·0	4·4	0·0	0·2	0·0	0·0
Karlsborg	S. 2·5	1215	136	438	11·7	81·3	3·5	25·8	12·6	1·1
Karlsborg	S. 4·2	2000 I.	58	25	1·7	8·0	0·0	0·0	0·0	0·0
Karlsborg	C.W. 3·9	I.	104	38	12·4	7·9	2·9	0·0	0·0	0·0
Konigswusterhausen	C.W. 5·2	I.	86	36	5·8	58·5	0·0	25·0	5·5	0·0

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Moscow	S.	4·8	I.	473	394	5·1	44·4	0·2	7·6	0·5	0·0
Nantes	S.	2·5	0800 2100	55	98	0·0	8·2	0·0	1·0	0·0	0·0
Nantes	S.	4·2	0810 2130	111	103	1·8	19·8	0·0	0·0	0·0	0·0
Nauen	S.	3·2	1150	226	—	3·5	—	0·0	—	—	—
Nauen	C.W.	4·7	I.	744	506	14·4	35·5	1·2	9·5	0·2	—
Ongar	C.W.	2·9	I.	1786	940	9·8	35·5	0·4	10·7	0·5	—
Ongar	C.W.	3·8	I.	1242	540	8·5	22·6	0·2	9·6	0·9	—
Ongar	C.W.	4·4	I.	1089	615	21·6	35·8	0·8	7·5	—	—
Paris	S.	2·6	0815	300	—	0·0	—	0·0	—	—	—
Paris	S.	2·6	0920	1616	322	0·2	1·5	0·0	0·0	0·0	0·0
Paris	S.	2·6	1920 1130 2155	399	29	0·0	6·9	0·0	0·0	0·0	0·0
Paris	S.	3·2	1200	200	—	0·5	—	0·0	—	—	—

I. = Irregular transmission.

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TABLE 15.—*Showing Percentage Variations of Bearings from the Annual Mean at Bristol*, 1922–23

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.						
					Over 2°.		Over 5°.		Over 10°.		Over 20°.
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Night.
	km.										
Aberdeen	C.W. 3·3	0830 1700	82	64	14·6	46·9	0·0	10·9	0·0	1·5	0·0
Air Ministry	C.W. 4·1	0800 1900	314	266	44·9	71·0	13·1	33·8	0·3	7·1	0·0
Aranjuez	C.W. 3·7	I.	239	140	6·7	61·4	0·0	20·7	0·0	7·9	0·7
Chelmsford	C.W. 3·8	I.	79	49	0·0	4·1	0·0	0·0	0·0	0·0	0·0
Clifden	S. 5·8	0950 2150	19	32	0·0	15·6	0·0	0·0	0·0	0·0	0·0
Clifden	C.W. 5·8	I.	166	212	0·6	0·0	0·0	0·0	0·0	0·0	0·0
Coltano	S. 4·2	I.	43	34	2·3	0·0	0·0	0·0	0·0	0·0	0·0
Devizes	C.W. 2·1	I.	35	101	17·1	44·5	2·9	6·9	0·0	0·0	0·0
Horsea	C.W. 5·0	I.	187	151	19·2	56·9	0·0	16·5	0·0	0·7	0·0

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Karlsborg	S. 2·5	1215 2000	27	324	3·7	67·1	0·0	21·6	0·0	7·1	1·2
Karlsborg	C.W. 3·9	I.	84	23	0·0	30·4	0·0	8·7	0·0	—	0·0
Karlsborg	C.W. 4·3	I.	92	33	41·4	60·6	9·8	30·3	1·1	21·2	0·0
Konigswusterhausen ..	C.W. 5·2	I.	464	78	10·1	35·9	0·0	14·1	0·0	5·1	0·0
Leafield (M)	C.W. 8·8	1200 2000	215	480	8·4	22·1	0·0	1·7	0·0	—	0·0
Leafield (S)	C.W. 8·7	1200 2000	169	378	7·1	26·2	0·0	2·2	0·0	0·3	0·0
Moscow	S. 4·8	I.	45	232	2·2	28·0	0·0	3·9	0·0	0·9	0·0
Nantes	S. 2·5	0800 2100	35	83	2·9	0·0	2·9	0·0	0·0	0·0	0·0
Nantes	S. 4·2	0815 2130	91	74	0·0	1·4	0·0	0·0	0·0	0·0	0·0
Nauen	S. 3·2	1150	182	—	0·0	—	0·0	—	0·0	—	—
Nauen	C.W. 4·7	I.	454	548	13·0	55·1	2·2	25·7	0·0	6·2	1·3
Nauen	C.W. 6·3	I.	22	54	36·4	27·8	0·0	22·2	0·0	9·3	0·0
Northolt	C.W. 7·0	I.	50	49	8·0	89·8	0·0	61·2	0·0	12·2	0·0
Northolt	C.W. 6·9	I.	49	49	18·0	93·9	2·0	59·2	0·0	12·2	0·0
Ongar	C.W. 2·9	I.	251	246	21·9	87·4	2·8	61·0	0·0	32·5	7·3
Ongar	C.W. 3·8	I.	588	335	15·0	44·9	1·4	27·5	0·0	6·6	0·0
Ongar	C.W. 4·4	I.	287	321	15·3	68·3	0·0	45·8	0·0	13·1	2·2

I. = Irregular transmission.

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TABLE 15.—*Showing Percentage Variations of Bearings from the Annual Mean at Bristol*, 1922-3—continued

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.						
					Over 2°.		Over 5°.		Over 10°.		Over 20°.
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Night.
	km.										
Paris	S. 2·6	0815	158	—	0·0	—	0·0	—	0·0	—	—
Paris	S. 2·6	0920 1920	900	193	0·1	0·5	0·0	0·0	0·0	0·0	0·0
Paris	S. 2·6	1130 2155	174	64	0·0	26·6	0·0	1·6	0·0	0·0	0·0
Paris	S. 3·2	1200	88	—	0·0	—	0·0	—	0·0	—	—
Paris (M)	C.W. 7·6	I.	41	—	14·6	—	0·0	—	0·0	—	—
Paris (S)	C.W. 7·5	I.	35	—	20·0	—	0·0	—	0·0	—	—
Paris (UFP)	C.W. 2·4	I.	98	73	61·2	68·2	18·4	21·9	0·0	2·7	0·0
Poldhu	S. 2·8	0950 2150	25	—	0·0	—	0·0	—	0·0	—	—
Stonehaven	C.W. 4·5	I.	166	88	3·6	54·6	1·2	23·9	0·0	3·4	0·0
Whitehall	C.W. 3·3	0900 1700	113	53	34·5	64·1	3·5	24·5	0·0	1·9	0·0

I = Irregular transmission.

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TABLE 16.—*Showing Percentage Variations of Bearings from the Annual Mean at Newcastle, 1922–23*

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)	
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.							
					Over 2°.		Over 5°.		Over 10°.		Over 20°.	
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
	km.											
Aberdeen	C.W. 3·3	0830 1700	189	125	37·0	63·1	6·3	28·0	0·5	13·6	0·0	0·0
Aberdeen	C.W. 3·3	2100	—	111	—	82·0	—	49·5	—	10·1	—	0·0
Air Ministry ..	C.W. 4·1	I.	247	252	17·0	33·3	0·8	8·3	0·0	1·6	0·0	0·0
Berne	C.W. 3·4	I.	530	217	3·2	61·3	0·4	32·7	0·0	10·6	0·0	1·8
Budapest	S. 3·0	I.	48	26	2·1	15·4	0·0	0·0	0·0	0·0	0·0	0·0
Chelmsford ..	C.W. 3·8	I.	76	70	9·2	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Cleethorpes ..	C.W. 4·3	0800	118	—	30·5	—	2·5	—	0·0	—	0·0	—
Cleethorpes ..	C.W. 4·3	I.	116	187	12·9	61·0	0·0	13·9	0·0	0·5	0·0	0·0

I. = Irregular transmission.

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TABLE 16.—*Showing Percentage Variations of Bearings from the Annual Mean at Newcastle*, 1922-23—continued

(1)	(2)	(3)	(4)		(5)		(6)		(7)		(8)	
Transmitting Station.	Type and Wave-length.	Time of Trans-mission.	Total Number of Observations.		Percentage Variations from Annual Mean.							
					Over 2°.		Over 5°.		Over 10°.		Over 20°.	
			Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
	km.											
Clifden	S. 5·8	0950 2150	85	66	0·0	28·8	0·0	9·1	0·0	0·0	0·0	0·0
Clifden	C.W. 5·8	I.	316	594	0·0	6·9	0·0	3·4	0·0	1·2	0·0	0·0
Coltano	S. 4·2	I.	169	244	1·0	16·4	0·0	1·0	0·0	0·0	0·0	0·0
Horsea	C.W. 5·0	I.	193	98	23·8	39·8	2·6	10·2	0·0	0·0	0·0	0·0
Karlsborg ..	S. 2·5	1215 2000	171	485	20·5	83·5	0·0	42·5	0·0	20·2	0·0	1·9
Karlsborg ..	S. 4·2	I.	125	53	6·4	50·9	0·0	18·9	0·0	7·5	0·0	0·0
Karlsborg ..	C.W. 3·9	I.	503	237	11·3	40·0	0·6	16·9	0·0	8·5	0·0	2·1
Konigswuster-hausen	C.W. 5·2	I.	501	260	14·2	49·6	0·0	18·1	0·0	4·2	0·0	0·4
Moscow	S. 4·8	I.	421	945	0·5	21·9	0·0	6·6	0·0	1·7	0·0	0·2

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Nantes	S. 2·5	0800 2100	21	94	0·0	26·6	0·0	5·3	0·0	0·0	0·0	0·0
Nantes	S. 4·2	0810 2130	84	93	2·4	35·5	0·0	8·6	0·0	1·1	0·0	0·0
Nantes	S. 2·5	1215	60	—	6·7	—	0·0	—	0·0	—	0·0	—
Nauen	S. 3·2	1150	250	—	2·0	—	0·0	—	0·0	—	0·0	—
Nauen	C.W. 4·7	I.	1421	1471	17·7	52·7	6·8	23·9	2·2	5·9	0·3	0·6
Ongar	C.W. 2·9	I.	904	979	19·3	50·2	0·1	24·9	0·0	5·9	0·0	0·6
Ongar	C.W. 3·8	I.	1239	859	2·1	34·7	0·1	14·8	0·0	2·7	0·0	0·0
Ongar	C.W. 4·4	I.	252	321	4·7	24·0	0·4	10·6	0·0	1·6	0·0	0·0
Paris	S. 2·6	0815	277	—	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Paris	S. 2·6	0920 1920	1486	432	3·0	1·4	0·0	0·0	0·0	0·0	0·0	0·0
Paris	S. 2·6	1130 2155	516	162	0·0	23·4	0·0	2·5	0·0	0·0	0·0	0·0
Paris	S. 3·2	1200	114	—	0·0	—	0·0	—	0·0	—	0·0	—
Poldhu	S. 2·8	0950 2150	42	37	0·0	65·0	0·0	27·0	0·0	8·1	0·0	5·4
Sofia	S. 3·2	I.	—	163	—	45·4	—	16·5	—	3·7	—	0·6
Whitehall ..	C.W. 3·3	0900 1700	43	37	30·2	46·0	0·0	0·0	0·0	0·0	0·0	—
Whitehall ..	C.W. 3·3	2100	—	30	—	40·0	—	10·0	—	0·0	—	0·0

I = Irregular transmission.

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(13) *Extent of variations at short distances*

In discussing above the excessive night variations in observed bearings it was pointed out that for ranges of transmission of about 100 miles the variations appeared to be of the same order as those for ranges of 700 miles and upwards. As will be noticed on reference to the chart at the end of this report, the transmitting and observing stations were so situated that the path of transmission was entirely overland in all cases in which the range was less than 200 miles. Table 17 below shows that the variations are still serious when the range of transmission is as short as 30 miles for overland working.

TABLE 17.—*Variations at Distances less than* 100 *miles*

(1)	(2)	(3)	(4)
Observing Station.	Transmitting Station.	Distance.	Extreme Variation.
		(miles)	(deg.)
Aberdeen	Aberdeen	4·6	2·1
,, ...	Stonehaven	16	4·7
Bristol	Horsea	78	18·9
,, ...	Leafield	51	15·8
,, ...	Northolt	88	31·0
Cambridge	Ongar	34	10·0
Peterborough ..	Air Ministry ..	79	14·2
,, ..	Leafield	77	99·5
,, ..	Ongar	64	24·7
Teddington	Air Ministry ..	17	5·3
,, ...	Chelmsford	41	16·0
,, ...	Leafield	60	42·0
,, ...	Ongar	30	16·0
,, ...	Whitehall	10	4·6

For distances up to 17 miles, however, the extreme variations at night are of the same order as in the day-time. For example, Air Ministry at Teddington has given an extreme variation of the same order (5°–6°) for both day and evening periods. The records show that in this case the extreme difference from the mean of the several hundred bearings observed was only 4·5°, while nearly 99 per cent. of the readings were within 2°. In the case of Ongar at Teddington, however, 14 per cent. of the night bearings differed by more than 2°, as against 1·6 per cent. of the day bearings.

It is to be concluded from these results, therefore, that the variation in observed bearings associated with the term " night effect " on radio direction-finders commences to be serious when the transmission is entirely overland and for a distance exceeding 30 miles, whereas at distances of 17 miles and less the variations

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at night are similar to those experienced by day, both being of the order of 2°. While these deductions are made from observations taken on wave-lengths in the range 2,000 to 9,000 metres, later results discussed in Part III of this report have confirmed them for shorter wave-lengths. This later part of the investigation has also shown that the conclusions require to be modified when the path of transmission is entirely oversea.

(14) *Comparison of results on damped and undamped waves*

One of the objects of converting the direction-finders to continuous-wave reception was to enable a comparison to be made of the effects experienced on both damped and undamped wave transmissions. It has already been mentioned on p. 51 and Table 12 that the maximum amplitudes and proportions of the variations experienced on damped-wave stations were of the same order as those obtained on undamped waves. On a first inspection of the results it appears that the variations are much more serious on the undamped waves, but a closer inspection, having due regard to the greatly varying conditions, tends to lead to a reverse conclusion. In reviewing the results, it should be remembered that during the year under discussion about 80 per cent. of the observations were made on undamped waves, due to the simultaneous reduction of damped-wave transmitting stations and the increase in the number and power of the undamped-wave stations. For a true comparison of the effect of the wave damping, the two kinds of transmission should take place from the same station and preferably from the same aerial, on the same wave-length and at very similar periods. Among the observations being considered in this report, the only two transmitting stations which gave conditions approximating to the above were Clifden and Karlsborg, and in the following Table 18 is given a summary of the whole year's observations obtained on these stations.

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TABLE 18.—*Showing Comparative Results obtained on Damped and Undamped Wave Transmissions*

(1)	(2)	(3)	(4)			(5)		
			Day Observations.			Night Observations.		
Transmitting Station.	Type of Transmission and Wave-Length.	Observing Station.	No.	Extreme Variation.	Percentage more than 2° from Mean.	No.	Extreme Variation.	Percentage more than 5° from Mean.
	(km.)			(deg.)			(deg.)	
Clifden	S. 5·8	Aberdeen	19	3·0	0·0	35	6·8	0·0
,, ...	C.W. 5·8	,, ...	189	5·0	2·1	573	4·1	0·0
,, ...	S. 5·8	Bristol	19	0·7	0·0	32	6·2	0·0
,, ...	C.W. 5·8	,, ...	166	5·6	1·0	212	3·9	0·0
,, ...	S. 5·8	Newcastle	85	1·5	0·0	66	12·5	9·1
,, ...	C.W. 5·8	,, ...	316	2·3	0·0	594	26·0	3·4
,, ...	S. 5·8	Teddington	34	1·5	0·0	62	15·7	14·5
,, ...	C.W. 5·8	,, ...	153	5·7	4·6	389	38·5	9·8

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Karlsborg	S. 2·5	Aberdeen	—	—	—	259	32·3	59·5
„	C.W. 3·9	„	436	4·8	0·9	242	34·3	9·9
„	S. 2·5	Bangor	32	2·8	0·0	257	34·4	28·4
„	C.W. 3·9	„	540	10·8	7·6	291	51·1	19·2
„	S. 2·5	Birmingham ..	136	5·8	11·7	438	47·5	25·8
„	C.W. 3·9	„	104	9·3	11·6	38	7·5	0·0
„	S. 2·5	Bristol	27	5·2	3·7	324	41·0	21·6
„	C.W. 3·9	„	84	2·5	0·0	23	11·9	8·7
„	S. 2·5	Newcastle	171	6·6	20·5	485	57·5	42·5
„	C.W. 3·9	„	503	10·5	11·3	237	55·0	16·9

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It is seen from this table that although in some cases both day and by night the extreme errors appear to be slightly greater on undamped waves, at night the proportion of the errors is less on undamped than on damped waves. The actual differences tabulated are probably not significant, and the deduction can therefore be made that, providing the necessary precautions are taken with the D.F. receiving apparatus as described elsewhere,[1] no difference in the ordinary night variations is experienced with the use of either damped or undamped waves.

(15) *Failure to obtain bearings*

It is not considered necessary to repeat here the analysis of the cases in which a bearing was unable to be taken, as was done in the previous report. It proved difficult to keep a systematic record of such items as interference and atmospherics without seriously hindering the main purpose of the investigation. Owing to the increased scope of the observing stations made possible by continuous wave working, and the considerable increase in the number of high-power stations available, little difficulty was experienced in the way of interference during this second year's observations.

Also, for the reasons given in the previous report, it was not feasible always to observe the sharpness of the signal minimum. The number of cases in which the minimum was so blunt that it was not possible to obtain a suitable observation was much more marked at Bangor than elsewhere, the proportion of such instances amounting to 20 or 30 per cent. of the total observations on some transmitters. At all the other observing stations, however, the number of cases in which no observation could be made from the above cause was always less than 9 per cent. and very frequently less than 1 per cent. Further discussion of this point will be given in connection with the work on shorter wave-lengths, which will follow in Part III of the report.

SECTION IV.—OBSERVATIONS OVER 24-HOUR PERIODS

(16) *General*

With the extension of the investigation to undamped wave working, advantage was taken of the almost continuous transmissions from some stations employing undamped waves to make observations of bearings at regular intervals for a period of 24 hours. Such a long period of observations could only be carried out where two observers were available at each station and the tests were ultimately confined to the stations at Birmingham, Bristol and Newcastle. The first of such tests was carried out on 26th to 27th January, 1923, and they were repeated at approximately fortnightly intervals, the observations concluding on 30th June, 1923, after a total of twelve

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tests. The 24-hour period in every case commenced at midday, so that continuous observation was maintained during one night with the odd hours of daylight remaining at each end. Certain transmitting stations known to be working for long periods at a time were selected for these observations and a programme was drawn up to synchronise as far as possible the three observing stations. From four to six transmitting stations were used in each of those tests and a bearing observation was taken successively on each, the whole cycle of observations being repeated regularly every six minutes (later, twelve minutes). By thus securing regular and simultaneous observations of each transmitter at the three receiving stations a much closer comparison of the records may be carried out. During these tests, 13,760 observations were made and a complete summary of these is given in the following Tables 19–21.

In these tables no distinction has been made between the day and night periods as previously defined, and thus it is natural to find the percentage variations slightly smaller than those given above (12), since the night readings have been somewhat diluted by the much smaller day errors. These tables present the usual features which have already been discussed in detail, but attention may be drawn to two interesting points. First, the variations experienced at Newcastle on the transmissions from Nauen (viz., 140·5°) are the largest that have been recorded in the whole two years of this investigation. The extreme readings correspond to an actual error in bearing of 105·2°, there being only one reading over 100°, and only three readings exceeding 90°; and as shown for this particular case in Table 21, only 2 per cent. of the total readings exceed 20° in error. When it is remembered that the number of results dealt with in both this and the previous report is nearly 164,000, the rarity of errors of bearing of the order of 90° will be appreciated. The second point to be noticed is that, in the cases where the direction of transmission approximates to the N.S. line, the variations do appear to be of a smaller magnitude than in the cases where the direction of transmission is more nearly E. and W. This result is particularly prominent in the case of the three Ongar transmitting stations, as observed at Newcastle and Bristol respectively.

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TABLE 19.—*Summary of Observations taken at Birmingham during 24-hour Tests from January to June,* 1923

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)		
Transmitting Station.	Wave-length.	Distance.	True Bearing.	Number of Observations.	Error of Mean Bearing.	Extreme Variation.	Maximum Variation from Mean.	Percentage of Bearings differing from Mean by more than—		
								2·0°	5·0°	10·0°
	(km.)	(miles)	(deg.)		(deg.)	(deg.)	(deg.)			
Air Ministry ..	3·3	130	128·6	205	+ 2·2	15·6	+ 8·6	27·8	6·9	0·0
Berne	3·3	562	128·3	379	+ 1·9	15·0	+ 9·0	10·5	1·6	0·0
Konigswuster-hausen.	5·3	657	84·7	365	+ 2·6	21·2	+11·9	25·5	3·8	0·3
Nauen	4·7	621	82·8	178	+ 3·5	24·0	−18·3	23·6	7·3	1·7
Ongar	2·9	104	119·0	1,081	+ 2·3	25·9	−13·7	23·9	8·2	0·6
,, ...	3·8	104	119·0	757	+ 2·5	20·6	−11·0	19·0	5·1	0·3
,, ...	4·4	104	119·0	1,226	+ 2·9	19·2	− 9·9	39·5	10·5	0·0

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TABLE 20.—*Summary of Observations taken at Bristol during 24-hour Tests from January to June, 1923*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)			
Transmitting Station.	Wave-length.	Distance.	True Bearing.	Number of Observations.	Error of Mean Bearing.	Extreme Variation.	Maximum Variation from Mean.	Percentage of Bearings differing from Mean by more than—			
								2·0°	5·0°	10·0°	20·0°
	(km.)	(miles)	(deg.)		(deg.)	(deg.)	(deg.)				
Air Ministry ..	3·3	112	88·6	107	− 2·7	19·3	+10·1	53·2	27·1	0·9	0·0
Berne	3·3	547	120·3	437	+ 0·8	34·6	−17·9	18·1	7·8	4·8	0·0
Konigswusterhausen.	5·3	695	78·8	612	− 2·2	32·8	−20·9	28·9	10·1	2·8	0·2
Nauen	4·7	662	76·8	830	− 1·4	62·0	−32·4	44·6	20·6	5·3	1·2
Ongar	2·9	120	81·1	1,048	− 1·1	53·6	−36·1	40·0	22·3	9·9	2·1
,, ...	3·8	120	81·1	750	− 1·3	48·9	−27·6	29·7	15·7	4·8	0·7
,, ...	4·4	120	81·1	1,227	− 2·8	61·8	−37·0	55·7	33·0	12·4	1·1

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TABLE 21.—*Summary of Observations taken at Newcastle during 24-hour Tests from January to June,* 1923

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)			
Transmitting Station.	Wave-length.	Distance.	True Bearing.	Number of Observations.	Error of Mean Bearing.	Extreme Variation.	Maximum Variation from Mean.	Percentage of Bearings differing from Mean by more than—			
								2·0°	5·0°	10·0°	20·0°
	(km.)	(miles)	(deg.)		(deg.)	(deg.)	(deg.)				
Air Ministry ..	3·3	252	162·5	72	0·0	10·9	+ 6·9	13·9	1·4	0·0	0·0
Berne	3·3	676	140·8	532	− 2·2	36·8	−20·8	11·7	8·7	3·2	0·2
Konigswuster-hausen.	5·3	658	100·0	681	− 2·9	45·2	−26·6	26·6	5·7	2·1	0·1
Nauen*	4·7	612	99·2	687	+ 0·6	140·5*	+105·2*	65·2	19·4	4·5	2·0
Ongar	2·9	238	160·2	1,058	− 2·6	44·3	+24·7	24·9	9·2	2·1	0·1
,, ...	3·8	238	160·2	775	+ 0·3	29·1	−14·7	9·2	2·3	0·8	0·0
,, ...	4·4	238	160·2	753	− 0·3	22·4	+12·1	23·0	7·8	0·5	0·0

* Three readings over 90° and one reading over 100° from mean.

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(17) *Graphs of individual bearings*

From these records taken during the 24-hour periods a large number of graphs have been plotted which show each individual bearing observed. A selection of the graphs is given in Figs. 21 to 30.

Representative graphs for two of the Ongar transmitting stations are shown in Figs. 21–24, for tests made in January and June respectively. These may be taken as typical of the results obtained in the midwinter and midsummer conditions prevailing during the above months. They illustrate the decreased amplitude of the variations experienced at Newcastle as against that at Bristol as discussed above. Next there is seen to be no definite similarity in the manner of the variations experienced on the different wave-lengths of the two transmitters.

Among the observations taken in January, and illustrated in Figs. 21 and 22, it is seen that quite appreciable variations are taking place in the daylight hours, and that these increase considerably within about an hour before sunset. The results obtained in June, as illustrated in Figs. 23 and 24, however, show that the daylight variations are not appreciable except in the immediate neighbourhood of sunrise and sunset. Unfortunately, owing to the discontinuities in the transmissions at about the time of sunrise, the actual variation in the observed bearings at this time is not well brought out, but it is indicated that the effects are similar to those experienced at sunset.

In Figs. 25–27, results are illustrated for several transmitting stations as observed at Bristol in the months of February, April and May. These graphs confirm what has been stated above, viz., that in the summer months the variations are practically confined to the period included between the time of one hour before sunset until one hour after sunrise, but as winter conditions are approached the limits of this period increase considerably, until in midwinter the variations are taking place during the whole period of daylight, although they are then not so violent as during the hours of darkness. This confirms the excessive " day " variations which have been experienced in the general investigation during the winter months as discussed in Section II (4), p. 28. Reverting to Figs. 25–27, it will be seen that there is no marked difference between the results obtained on Ongar, a near-by transmitting station, and those obtained on the more distant stations of Nauen and Berne. Excepting the points noticed above there is no similarity between the variations observed at the same station on different transmissions from either the same or different stations. All the transmissions give rise to large and erratic variations during the whole of the night period and there is no time of maximum or minimum effect during this period.

In much the same way, and with the same limitations as noted above, there is no similarity in the variations experienced on the

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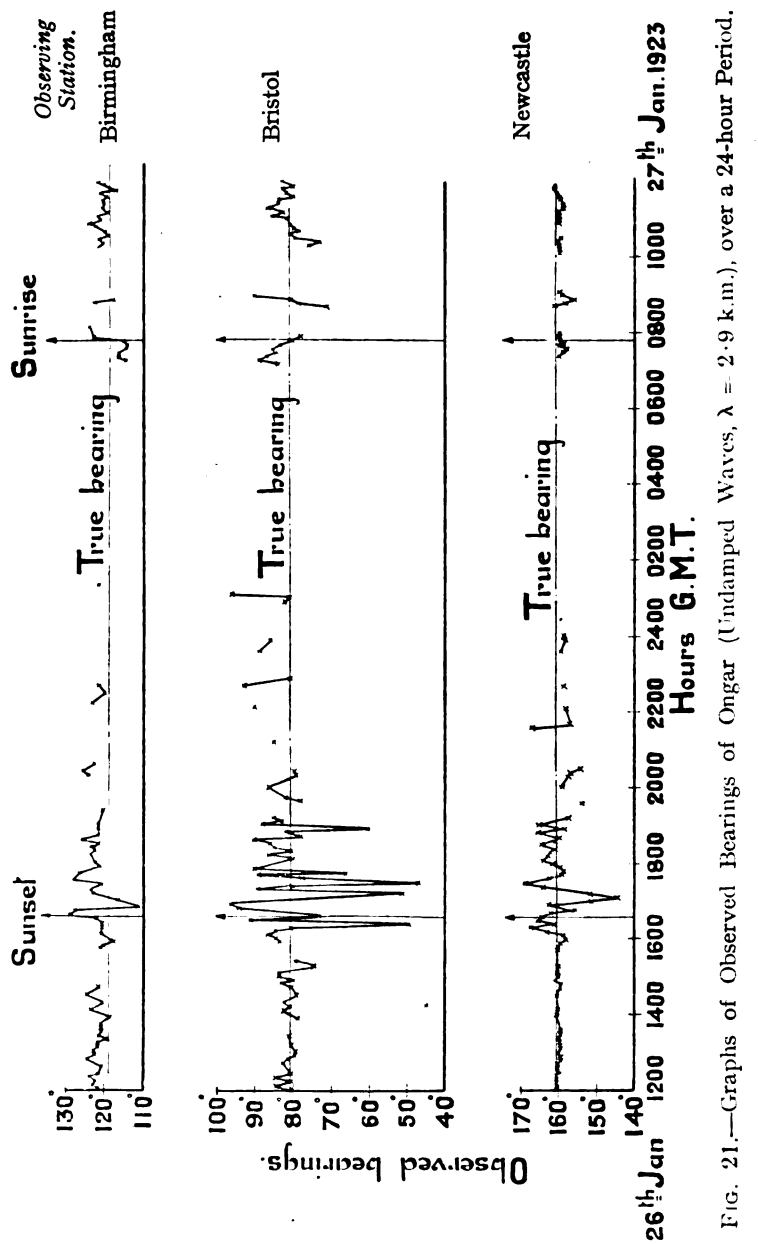

FIG. 21.—Graphs of Observed Bearings of Ongar (Undamped Waves, $\lambda = 2{\cdot}9$ k.m.), over a 24-hour Period.

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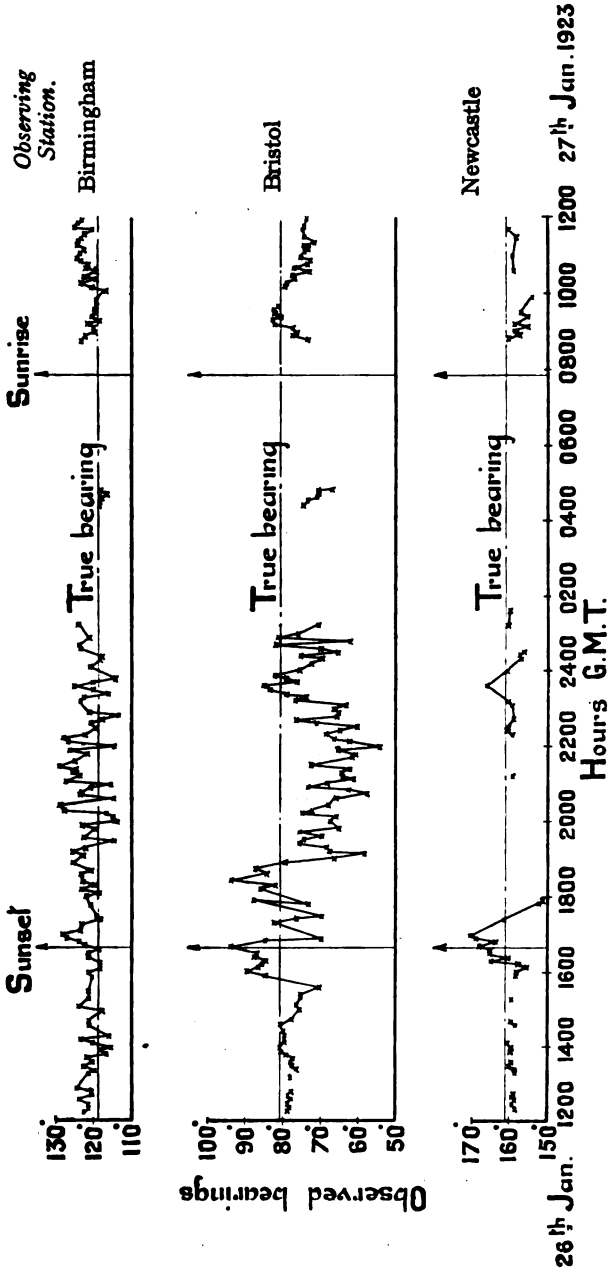

FIG. 22.—Graphs of Observed Bearings of Ongar (Undamped Waves, $\lambda = 4{\cdot}4$ k.m.) over a 24-hour Period.

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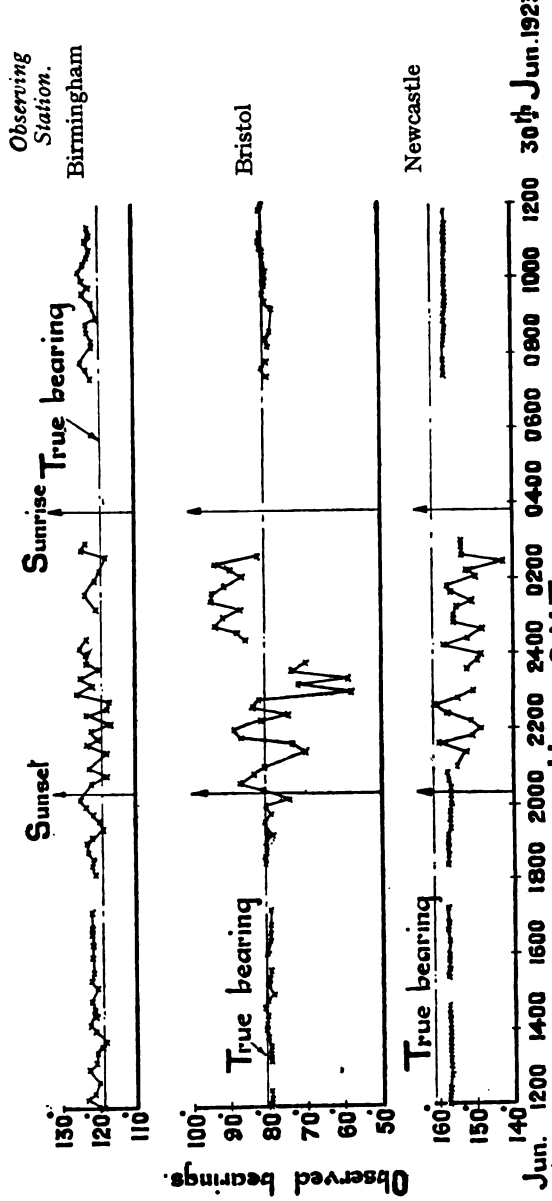

FIG. 23.—Graphs of Observed Bearings of Ongar (Undamped Waves, $\lambda = 2{\cdot}9$ k.m.) over a 24-hour Period.

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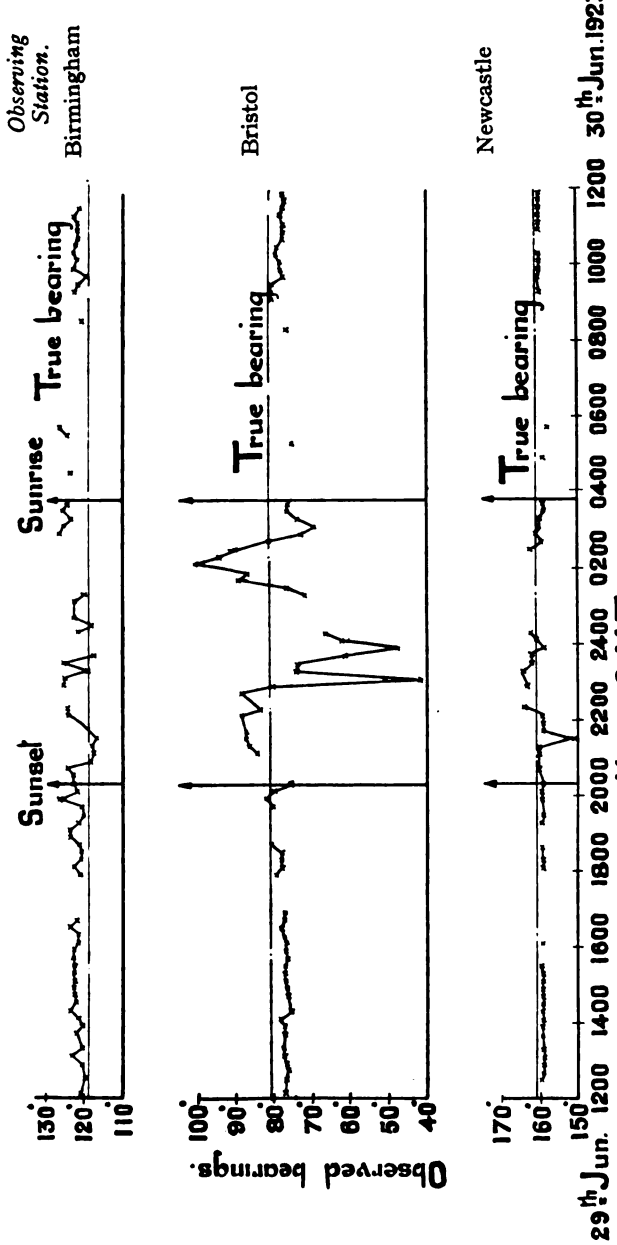

FIG. 24.—Graphs of Observed Bearings of Ongar (Undamped Waves, $\lambda = 4{\cdot}4$ k.m.) over a 24-hour Period.

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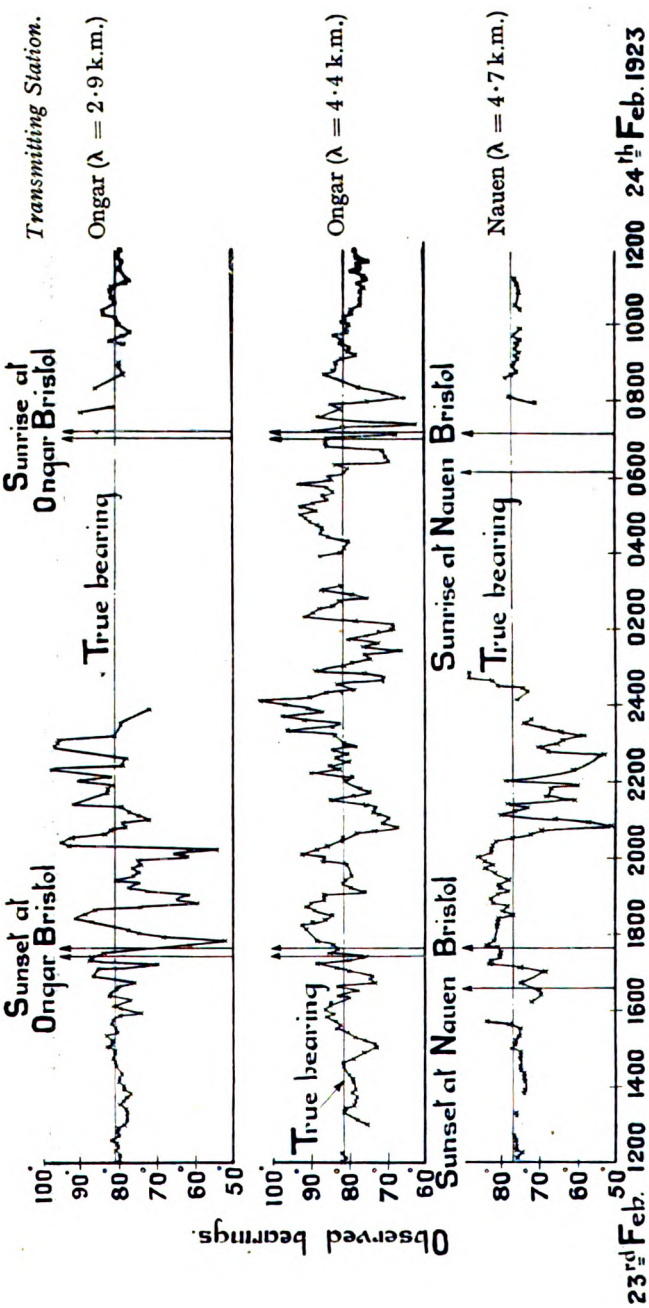

FIG. 25.—Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 k.m.) and Nauen (Undamped Waves, λ = 4·7 k.m) at Bristol over a 24-hour Period.

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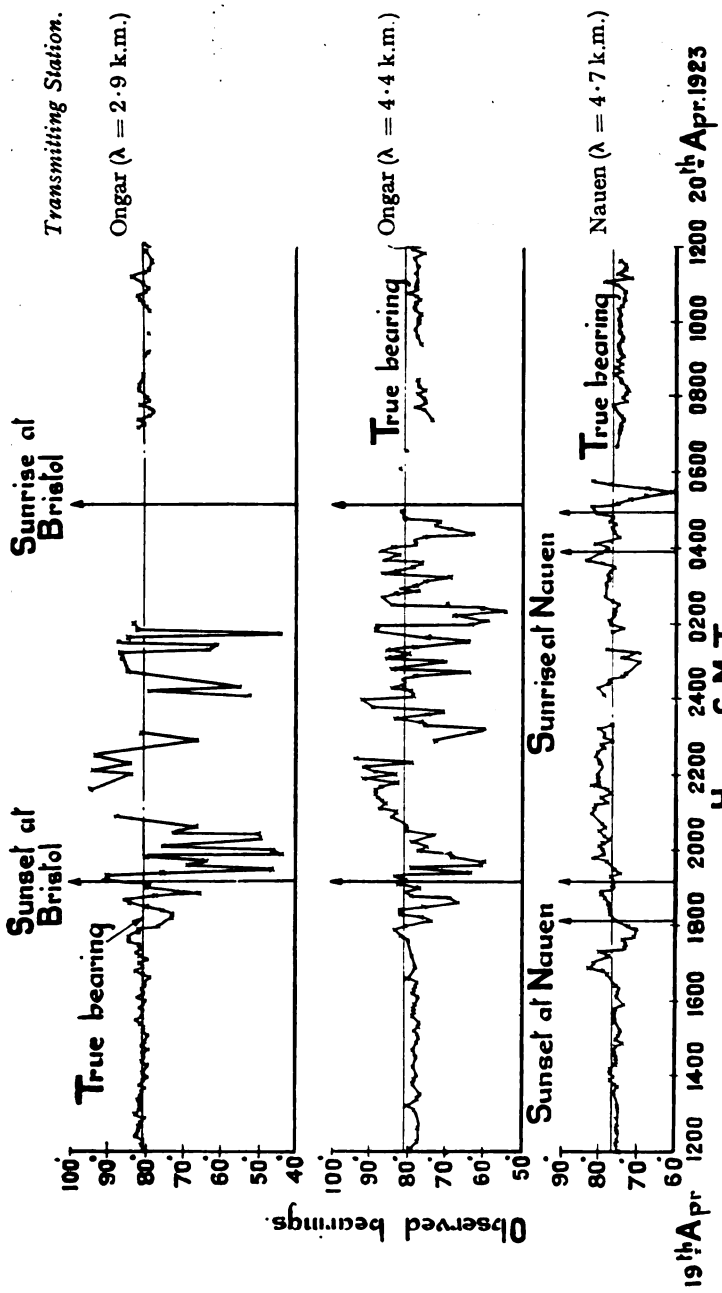
Transmitting Station.
Ongar (λ = 2·9 k.m.)
Sunrise at Bristol
Sunset at Bristol
True bearing
Ongar (λ = 4·4 k.m.)
True bearing
Sunrise at Nauen
Sunset at Nauen
Nauen (λ = 4·7 k.m.)
True bearing
Observed bearings.
Hours G.M.T.
19th Apr 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 20th Apr. 1923

FIG. 26.—Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 k.m.) and Nauen (Undamped Waves λ = 4·7 k.m.) at Bristol over a 24-hour Period.

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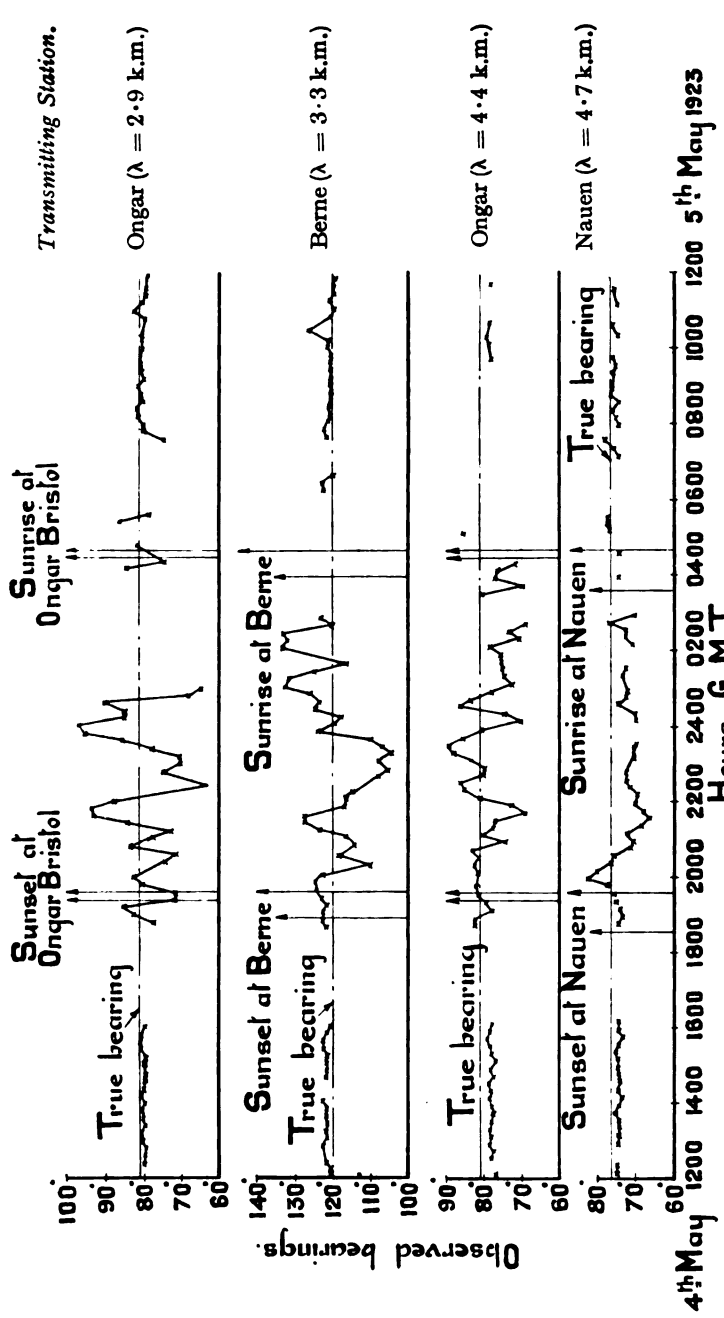
Transmitting Station.
Sunset at Ongar Bristol
Sunrise at Ongar Bristol
True bearing
Ongar (λ = 2·9 k.m.)
Sunset at Berne
Sunrise at Berne
True bearing
Berne (λ = 3·3 k.m.)
Sunset at Nauen
Sunrise at Nauen
True bearing
Ongar (λ = 4·4 k.m.)
Nauen (λ = 4·7 k.m.)
Observed bearings.
Hours G.M.T.
4th May 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 5th May 1923

FIG. 27.—Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 k.m.), Nauen (Undamped Waves, λ = 4·7 k.m.) and Berne (Undamped Waves, λ = 3·3 k.m.) at Bristol over a 24-hour Period.

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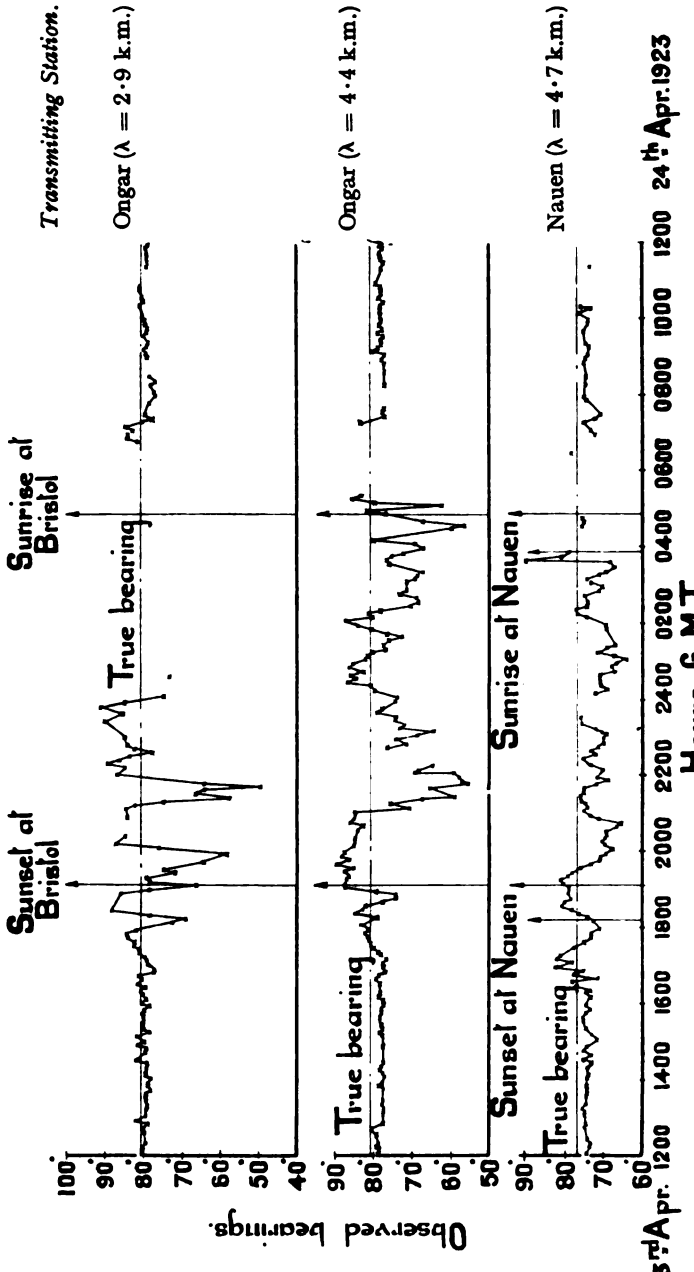
Transmitting Station.
Ongar (λ = 2·9 k.m.)
Ongar (λ = 4·4 k.m.)
Nauen (λ = 4·7 k.m.)
Sunset at Bristol
Sunrise at Bristol
Sunset at Nauen
Sunrise at Nauen
True bearing
Observed bearings.
Hours G.M.T.
23rd Apr. 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 24th Apr. 1923

FIG. 28.—Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 k.m.), and Nauen (Undamped Waves, λ = 4·7 k.m.) at Bristol over a 24-hour Period.

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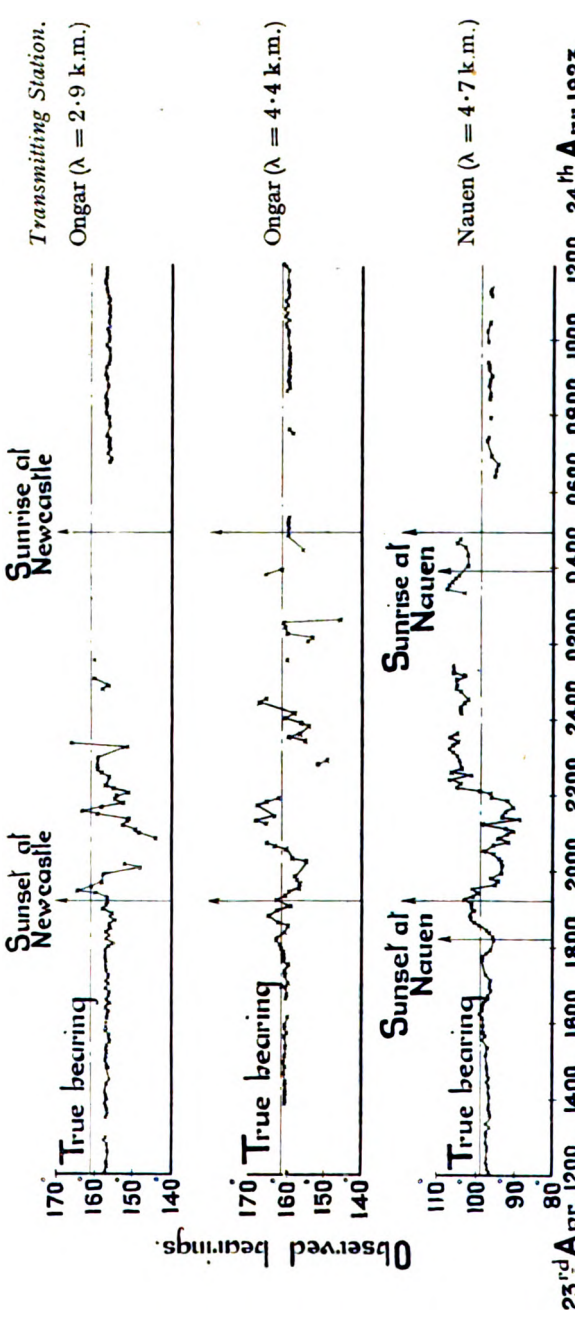
Transmitting Station.
Ongar (λ = 2·9 k.m.)
Ongar (λ = 4·4 k.m.)
Nauen (λ = 4·7 k.m.)
Sunset at Newcastle
Sunrise at Newcastle
Sunset at Nauen
Sunrise at Nauen
True bearing
Observed bearings.
Hours G.M.T.
23rd Apr. 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 24th Apr. 1923

FIG. 29.—Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 k.m.) and Nauen (Undamped Waves, λ = 4·7 k.m.) at Newcastle over a 24-hour Period.

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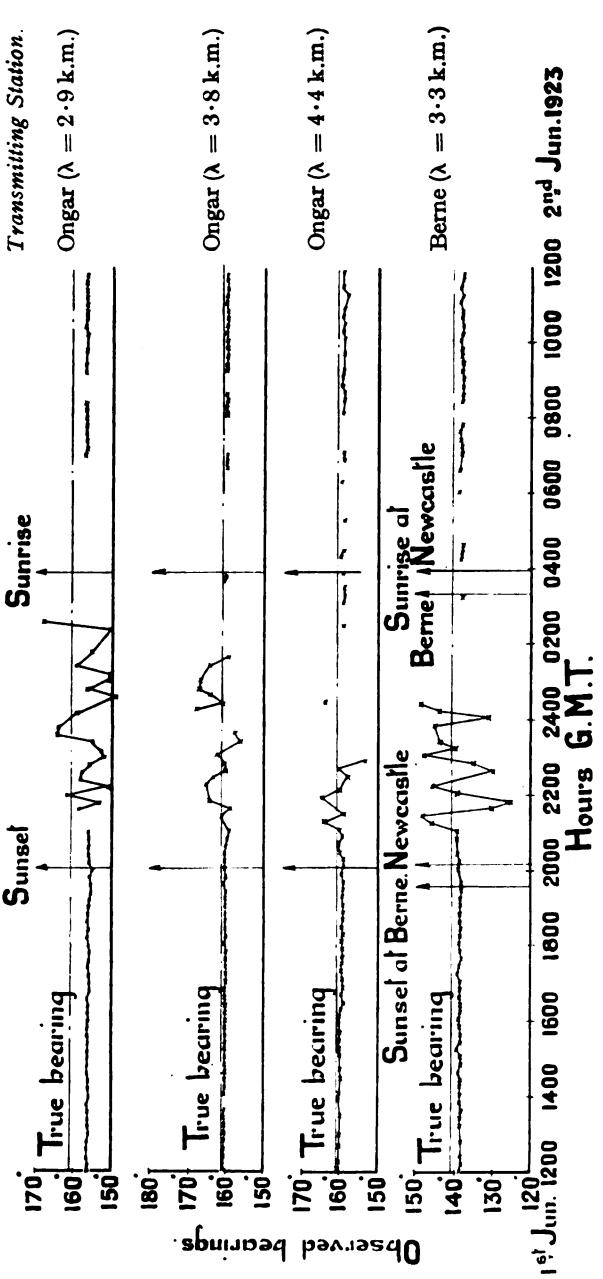
Transmitting Station.
Ongar (λ = 2·9 k.m.)
Ongar (λ = 3·8 k.m.)
Ongar (λ = 4·4 k.m.)
Berne (λ = 3·3 k.m.)
Sunset
Sunrise
Sunset at Berne.
Sunrise at Berne & Newcastle
True bearing
Observed bearings.
Hours G.M.T.
1st Jun. 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 2nd Jun. 1923

FIG. 30.—Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9, 3·8 and 4·4 k.m.) and Berne (Undamped Waves, λ = 3·3 k.m.) at Newcastle over a 24-hour Period.

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same transmissions at different observing stations. This point is illustrated by Figs. 28 and 29, which show the simultaneous observations made at Bristol and Newcastle in April, 1923. These and the previous curves given in Figs. 21–24 show that it is quite possible for one station to experience a large error in bearing which is not observed at another station, and also that the direction of the error relative to the true bearing is not necessarily the same at all stations.

Lastly, Fig. 30 shows the comparative constancy of the observed bearings which may obtain under certain very favourable conditions. These results were taken in June, and the direction of transmission is about 40° and 20° W. of N. for the two transmitting stations, and these two factors evidently contribute to the good results. The extreme variations are seen to be about 2° except in the period from one hour *after* sunset to one hour *before* sunrise.

SECTION V.—SPECIAL OBSERVATIONS MADE IN NORTHERN LATITUDES

(18) *Extension of Investigation*

Following an agreement made between the representatives of Great Britain and Norway at the meeting at Brussels in 1922 of the Union Radiotélégraphique Scientifique Internationale, this investigation was extended to the taking of observations at a station situated at Lerwick, Shetland Islands, with the object of comparing the effects experienced in Northern Latitudes with those in England. Arrangements were made for the stations, Bergen and Fauske in Norway, to give special transmissions, according to a regular programme when not engaged upon other work. It was thus possible to keep under observation not only waves from the southerly stations but also those whose path of propagation was entirely in high latitudes.

These observations were not commenced until 30th July, 1923, by which date all the stations at the British Universities had been closed, but the analysis of the results obtained at Lerwick until the closing of the station on 19th April, 1924, is considered to be sufficient for the object in view. The observations were carried out during two daily periods of two hours each from Mondays to Fridays inclusive. In the early portion of the work these daily periods were separated by an interval of twelve hours, and each week the periods were moved forward by two hours, so as to cover the whole of the 24 hours. In the later part of the work the periods were fixed at 1100–1300 and 1900–2100 G.M.T.

(19) *Results obtained at Lerwick*

Table 22 is a summary of the 3,985 results obtained for all transmitting stations upon each of which more than thirty observations were made over the whole period.

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Table 23 gives an additional summary of the results in the form of the proportions of the observed bearings which differ by specific amounts from the mean observed bearings over the whole period. Since the periods of observation were widely distributed over the 24 hours, and it is convenient to classify them as " Day " and " Night " periods, it was assumed, from previous experience in this work, that the night period extended from one hour before sunset at the eastern end of the path of transmission to one hour after sunrise at the western end.

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TABLE 22.—*Summary of Observations taken at Lerwick from 30th July, 1923, to 19th April, 1924*

(1)	(2)	(3)	(4)	(5)				(6)			
				Day Observations.				Night Observations.			
Transmitting Station.	Type and Wave-length.	Distance.	True Bearing.	No.	Extreme Variation.	Error of Mean.	Max. Variation from Mean.	No.	Extreme Variation.	Error of Mean.	Max. Variation from Mean.
	(km.)	(miles)	(deg.)		(deg.)	(deg.)	(deg.)		(deg.)	(deg.)	(deg.)
Air Ministry	C.W. 4·1	600	175·0	16	2·0	− 5·0	+ 1·5	107	11·0	− 5·0	− 8·0
Bergen	C.W. 1·85	225	82·4	19	10·5	+ 3·3	+ 6·3	56	34·5	+ 2·7	+ 18·9
„	C.W. 2·4	225	82·4	259	5·5	− 8·5	+ 3·6	192	55·5	− 8·2	− 34·2
Budapest	C.W. 4·3	1,190	128·0	90	3·5	+ 3·9	− 1·9	228	21·0	+ 4·0	− 16·0
Fauske	S. 2·1	703	38·7	218	3·5	− 8·9	− 2·3	181	90·0	− 6·7	+ 73·0
Karlsborg	S. 2·5	562	94·9	35	7·0	− 4·5	+ 4·6	—	—	—	—
„	C.W. 2·5	562	94·9	122	12·0	− 1·7	− 7·2	—	—	—	—
„	C.W. 4·2	562	94·9	528	45·5	− 0·6	+25·2	448	90·0	+ 2·6	− 67·5
Ongar	C.W. 4·4	585	174·3	272	3·5	− 4·4	− 2·4	581	21·0	− 4·3	+ 13·0
Scheveningen	C.W. 1·8	593	157·0	66	8·5	+ 4·5	+ 5·0	—	—	—	—
Stonehaven	C.W. 4·5	225	190·6	216	8·0	− 6·4	+ 4·8	351	19·0	− 5·9	+ 9·8

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TABLE 23.—*Percentage Variations from Mean of Observations taken at Lerwick from 30th July, 1923, to 19th April, 1924*

(1)	(2)	(3)		(4)		(5)		(6)		(7)	
Transmitting Station.	Type and Wave-length.	Total Number of Observations.		Percentage Variations from Mean Bearings.							
				Over 2°		Over 5°		Over 10°		Over 20°	
		Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
	(km.)										
Air Ministry	C.W. 4·1	16	107	0·0	21	0·0	5	0·0	0·0	0·0	0·0
Bergen	C.W. 1·85	19	56	63	68	10	50	0·0	36	0·0	0·0
,, ...	C.W. 2·4	259	192	1	67	0·0	47	0·0	23	0·0	8
Budapest	C.W. 4·3	90	228	0·0	53	0·0	9	0·0	1	0·0	0·0
Fauske	S. 2·1	218	181	11	37	0·0	13	0·0	8	0·0	3
Karlsborg	S. 2·5	34	—	12	—	0·0	—	0·0	—	0·0	—
,, ...	C.W. 2·5	122	—	18	—	4	—	0·0	—	0·0	—
,, ...	C.W. 4·2	528	448	23	83	14	58	4	27	1	6
Ongar	C.W. 4·4	272	581	2	47	0·0	9	0·0	1	0·0	0·0
Scheveningen	C.W. 1·8	66	—	49	—	0·0	—	0·0	—	0·0	—
Stonehaven	C.W. 4·5	216	351	5	34	0·0	4	0·0	0·0	0·0	0·0

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(20) *Permanent deviations*

From the day observations recorded in Table 22 it is seen that the mean observed bearings on the various transmitting stations differ from the true bearings by amounts of from 0·6° to 8·5°, and that where a station has transmitted on two or more wave-lengths this error of the mean varies with the wave-length. In many cases the total variation of the day bearings is of the same or a less order than the actual error of the mean, so that it is unlikely that this represents a systematic error of the day variations. It was therefore suspected that the above " permanent " error of the observed bearings was due to some cause outside the immediate receiving apparatus. The site of the installation at Lerwick was by no means ideal from a direction-finding point of view, being on the top of a hill about 300 feet high. The surrounding land has a very broken coast-line and there are several hills of the order of 400 feet in height in the immediate vicinity. Under such geographical conditions, large errors of mean bearing, associated with abnormally large variations in bearing in the day-time, are to be expected. Compare, for example, the results obtained at Bangor and previously discussed in detail. The accuracy of the installation at Lerwick was checked by making simultaneous observations with a portable direction-finder, and it was found that a small change of one or two hundred yards in the position of the latter resulted in an alteration of several degrees of the bearings observed. This was considered to confirm the conclusion that the permanent errors were due to the local geographical features surrounding the direction-finder.

(21) *Day variations*

The day observations show that the range of variation of the apparent bearings is in general less than 10°, which is of the order to be expected in a hilly district when the range of transmission is from 200 to nearly 1,200 miles. In the case of one of the wave-lengths used by Karlsborg the extreme variations exceed the above amount and range up to the excessive figure of 45·5°. The worst variations in this case were observed at from one to three hours after sunrise at Lerwick, which occurs at slightly over one hour after sunrise at Karlsborg. The corresponding figures in Table 23 show that in most cases the percentage of the observations which are more than 5° different from the mean is very small, being highest in the case of Karlsborg mentioned above.

(22) *Night variations*

During the night periods the variations are seen to range up to the maximum value of 90°, the highest difference from the mean being 73°·0. It is to be noted that in spite of these large variations there is little difference between the errors of the day and night mean, showing that there is practically no systematic error which can be ascribed to the night bearings. A noticeable

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point in the results given in Tables 22 and 23, also, is that the variations are worse on the transmitting stations which lie in an easterly direction from Lerwick than on those to the south. This supports the fact previously observed in this investigation and discussed in some detail, that the variable errors on direction-finders tend to a minimum when the direction of transmission is North or South. The analysis given in Table 23 shows that in spite of these large variations during the night periods, an error exceeding 20° is a comparatively rare occurrence.

(23) *Conclusions*

It is to be concluded from these experiments that the conditions for wireless direction-finding in Northern Latitudes are not materially different from those which prevail over the British Isles. This conclusion must, however, be qualified by the conditions which prevailed during the above observations. It is possible that if experiments could be carried out in which the whole path of transmission was in a sufficiently high latitude, somewhat different effects might be experienced.

SECTION VI.—CONCLUSIONS

(24) *Concluding discussion on whole investigation*

Since this report completes the discussion of the results which have been obtained on the range of wave-lengths of from 2,000 to 9,000 metres, it will be useful to review briefly the main conclusions which have been drawn at various stages throughout both this and the previous Part of the report.

The permanent errors in bearing which were experienced at some direction-finding stations were found to be due to causes local to the station, such as the presence of mountains, metalwork and trees; and by choosing a suitable site for the station the magnitude of such errors could be reduced to 1° or 2°. The variable errors of the apparent bearings observed at all stations were found to be very erratic and numerous. In general the results were more erratic at Bangor than elsewhere, an effect which is probably to be ascribed to the mountainous country around this station. The largest error recorded during the whole two years' observations was over 105°, but errors of this magnitude were extremely rare, and out of the 164,000 observations tabulated only in three cases was an error exceeding 90° experienced. An arbitrary division of the times of observation into day and night periods was adopted for convenience in tabulating and discussing the results, the border line between these periods being one hour after sunrise at the westerly end of the path of transmission of the wireless waves to one hour before sunset at the easterly end. With this mode of separation it was found that the extreme error experienced in the day periods was usually about 4°, but during

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the winter months of the year this limit was considerably exceeded, apparently because of an extension of the night conditions until three or four hours after sunrise in the worst cases.

Even in the cases which fall within the above limit, the graphs illustrating the weekly and daily variation of the day readings show a small seasonal effect in the observations indicating greater variations in winter than in summer, but no similarity is displayed in the observed variations of either a given transmitter at several receiving stations or of several transmitters at a given receiving station. A characteristic of the day readings is that while, over a period of half an hour's observation, a variation exceeding one degree is comparatively rare, a sudden change in apparent bearing of two degrees or more may often take place from one day to the next. This suggests a stable condition on any one day, although this condition may vary from day to day, by an amount which is greater in winter than in summer. This point is of great significance and is now the subject of further investigation.

The mean apparent bearings observed during the night periods show no signs of a definite systematic error, and so the variations are on the whole equally distributed about the mean daily value. The maximum *variation* recorded at each observing station is of the order of 60° — 80°, a variation exceeding 90° being a rare occurrence. These values correspond to an extreme *error* in bearing of only about 45°, and, as mentioned above, an error of 90° is so rare as almost to be regarded as an accidental occurrence. The minimum distance at which these night variations have been experienced is 30 miles for overland working, observations taken at closer ranges than this showing a maximum error of only 2° or 3°. When the distance of transmission well exceeds the above limiting value—for example, 70–100 miles overland—the night variations experienced are very large and are of the same order as those experienced at all greater distances up to 1,500 miles (of which a large proportion was usually overland), which is about the limiting range of working in this investigation.

Within the limits employed in the observations, no behaviour of the apparent bearings has been attributable to either the wave-length or the use of damped or undamped waves; it being understood that a possible source of instrumental error, when using undamped waves, had been eliminated before commencing observations on these waves. Although the evidence on the point is somewhat conflicting, there are many suggestions among the observed readings that the night variations, while still being appreciable, tend towards a minimum magnitude when the direction of transmission approximates to the North and South line. From the graphs illustrating the weekly extremes of observed bearings it was concluded in Part I of the report* that no serious night variations commence until the sun has set over

* See Bibliography (p. 107)—ref. 2 pp. 68 and 78.

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the whole path of transmission. In many cases when the observations were taken on a distant transmitter situated east of the receiver, darkness prevailed at the transmitting station for upwards of one or two hours before any variations were experienced at the receiving end. The same general conclusion is reached for the long ranges of transmission from the further graphs of weekly extreme bearings accompanying this second part of the report, but it is found that for the short ranges up to about 150 miles the variations appear to have commenced prior to the passage of sunset over the path of transmission. In all cases however, it is found that after total darkness has prevailed over the whole range of transmission, the extent of the variations rapidly attains its night value and shows no signs of decrease until sunrise the following morning.

A study of the graphs plotted from the results of the 24-hour tests enables this analysis to be carried much further with more definite results. As already mentioned in the discussion of these results, the distinction between the day and night conditions from the point of view of variations is less marked in the winter than in the summer. It appears quite definitely from these graphs that the arbitrary division of the day and night periods is not a hard-and-fast rule which can be adopted to distinguish the times when night errors may be expected.

The chief effects to be observed appear now to be as follows. In the summer time in those latitudes in which the United Kingdom is situated, the variations experienced in daylight are very small, and these do not become serious until darkness has set over the whole path of transmission. Such variations then prevail throughout the night, but decrease to a negligible extent immediately at sunrise. As the seasonal conditions are changed gradually from summer to winter the variations in the daytime increase somewhat; the night conditions commence an appreciable time before sunset and continue until some time after sunrise. In the midwinter conditions represented by January, the change from day to night effects is very much more gradual and the difference is only distinguishable by the difference in magnitudes of the variations. At this time of the year it appears that the variations may have an amplitude of the order of 10° or more during all the daylight hours, and this increases rapidly at about one hour before sunset to the night value of 50° or 70°, and so continuing in the most erratic manner until one hour or so after sunrise.

This aspect of the results would appear to indicate that the effects cannot be subjected to a definite division between daylight and darkness, but rather that the variations are dependent upon the altitude of the sun and the intensity of its radiation in the lower* parts of the earth's atmosphere. For example, in Great Britain, the maximum altitude of the sun at 21st March, and 21st September is about 38°, increasing to 61° on 21st June

* For definition of " lower parts of the earth's atmosphere " see penultimate paragraph of this section on p. 106.

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and decreasing to 15° on 21st December. It appears likely that during the summer half-year between March and September, the intensity of the solar radiation is sufficient almost immediately after sunrise to produce the necessary effect, causing the cessation of the variations, whether this be ionisation of the lower atmosphere or not. As the season progresses, a longer time after sunrise must elapse before the radiation is sufficiently intense to stop the variations, until in the midwinter conditions, and due to the very low altitude of the sun, the radiation is not sufficiently intense at any time of the day to stop altogether the variations, but only to cause a decrease in their magnitude. This explanation would account for the comparatively large variations experienced even near midday in the winter months of November to February, and would also account for the very large day variations obtained in some cases at Lerwick, where of course the sun's altitude will be about 8° less than in England.

The consistency of the effects is being borne out by some observations which are still in progress at Slough on the U.R.S.I., signals from Leafield and Nantes, which are used for signal intensity measurements. The daily observation of bearings of these stations which are taken at 1400 in the afternoon show that the usual " night " effects began about the end of October and are still in progress. (February, 1925).

It should be pointed out that the expression " lower parts of the earth's atmosphere," used above, does not imply that part near the surface of the earth. No effect of rain, cloud or fog has ever been noticed on apparent bearings, and it is concluded that it is not the intensity of the solar radiation at the earth's surface which is important. This apparent connection between the altitude of the sun and variations in bearings suggests that the latter are due to the effect of the sun on the portion of the earth's atmosphere which is above the cloud level and below the level of permanent ionisation. This is a point, however, which must remain for closer investigation in the future.

(25) *Acknowledgments*

This investigation was carried out for the Radio Research Board, and the author is indebted to the Directional Wireless Committee of that Board for helpful advice and criticism.

The author wishes again to acknowledge his indebtedness to the observers detailed on page viii for the ready and efficient manner in which the observations were carried out to the author's instructions, and particularly to those who participated in the 24-hour tests, which were frequently, made under very adverse weather conditions.

Grateful acknowledgement is due to Mr. S. R. Chapman, M.Sc., for his continued assistance in the reduction of the large mass of observations recorded, and also to Messrs. E. L. Hatcher and A. C. Haxton for assistance in the preparation of tables and diagrams for this report

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SPECIAL REPORT NO. 4

VARIATIONS OF APPARENT BEARINGS OF RADIO TRANSMITTING STATIONS

PART III—OBSERVATIONS ON SHIP AND SHORE TRANSMITTING STATIONS, NOVEMBER, 1922—MARCH, 1924

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VARIATIONS OF APPARENT BEARINGS OF RADIO TRANSMITTING STATIONS

PART III—OBSERVATIONS ON SHIP AND SHORE TRANSMITTING STATIONS, NOVEMBER, 1922—MARCH, 1924

By R. L. Smith-Rose, Ph.D., M.Sc., D.I.C., A.R.C.Sc., A.M.I.E.E.
(of the National Physical Laboratory)

LONDON: PUBLISHED UNDER THE AUTHORITY
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INTRODUCTORY NOTE

FOLLOWING the scheme of this investigation as outlined in the previous reports, this publication forms Part III of the main Report. The period of these observations overlaps somewhat the period of those dealt with in Part II, and extends from November 1922 to the end of March 1924. The observations taken during this period were chiefly confined to those on the wave-lengths of 450 and 600 metres, although towards the end of the period some special experiments were made to obtain a direct comparison of the effects obtained on various moderate wave-lengths. The shorter wave-lengths employed correspond approximately with those used in the application of wireless direction-finding to marine navigation; and this, together with the fact that one of the observing stations was suitably located on the East Coast of England, was used to advantage in the compiling of a large amount of data which was of direct practical value in addition to the more purely scientific interest of the investigation as a whole. In this connection some of the observations discussed in the present report were taken on certain ship transmitters which sent special signals for the purpose. The results of these experiments have already been mentioned in previous reports, and are discussed in detail in the present one. They are considered to afford valuable evidence as to the reliability of wireless direction-finding at all times and its freedom from errors when employed under the usual conditions demanded for marine navigation.

A further departure from the usual routine of the other parts of the investigation was that on these shorter wave-lengths, Dr. Smith-Rose was enabled to make use of a transmitting station, erected at the National Physical Laboratory, Teddington, for the purpose of carrying out special experiments on such matters as the effect of the shape of the transmitting aerial and the effects of wave-damping and of wave-length. These experiments could only have been carried out by the aid of a transmitting station

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under the complete control of the investigator, and the results, which are described in their appropriate place in the report, are considered to have fully justified the employment of this station.

This report brings to a close the comprehensive investigation of variations of apparent bearings of wireless transmitting stations, but it is natural to find that a number of problems has arisen directly therefrom, and each of these is being investigated in the continuation of the work of Directional Wireless Committee.

F. E. SMITH,
Chairman of the
Committee on Directional Wireless.

April, 1926.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH,
16 Old Queen Street,
London, S.W.1.

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VARIATIONS OF APPARENT BEARINGS OF RADIO TRANSMITTING STATIONS

PART III—OBSERVATIONS ON SHIP AND SHORE TRANSMITTING STATIONS NOVEMBER, 1922–MARCH, 1924

SECTION I.—INTRODUCTORY

(1) *Extension of the investigation to shorter wave-lengths*

THE inauguration of the investigation into the variations of apparent bearings of wireless transmitting stations was described in the preface to Special Report No. 2.[1]* It will be recalled that the investigation was commenced (on wave-lengths of from 2,000 to 9,000 metres) by the installation of a number of Robinson frame coil direction-finders at various British Universities and Government experimental establishments. These observations were commenced on 7th February, 1921, and continued without a break until 30th June, 1923. Some further observations were carried out at a station in High Northern latitudes between July, 1923, and April, 1924. On a much reduced scale also daily observations have been made at one observing station from September, 1924, until December, 1925. All the above observations were confined to the comparatively long waves between the limits of 2,000 and 12,500 metres.

Very early in the progress of the investigation the desirability of extending its scope to much shorter waves was realised, and in July, 1922, arrangements were made to carry out these observations, special attention being given to the wave-length of 450 metres, which was at that time in general use for direction-finding in this country. Owing to the fact that only low-power transmitting stations were in operation on these wave-lengths and also that in general the amplifying receivers are less sensitive, it was not found possible to use the existing organisation of direction-finding installations for simultaneous observations on these waves. Two stations were eventually employed for this work, one of which was located at the Radio Research Board's experimental station at Slough, the other being a naval D.F. station loaned from the British Admiralty for experimental purposes. The latter station, situated at Orford, Suffolk, was already equipped with the Bellini-Tosi D.F. system, and as this system had reached a very advanced stage of development on the particular wave-lengths in question, similar apparatus was installed at Slough for this portion of the investigation.

* These numbers refer to the bibliography on p. 53.

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The station at Orford was situated within a few hundred yards of the East Coast of England and this gave an opportunity to study the comparative behaviour of direction-finders for transmission over land and sea respectively. The provision of a transmitting station at Orford also enabled many special experiments to be carried out under conditions and at times which would have been impracticable with the ordinary commercial transmitting stations.

SECTION II.—DESCRIPTION OF INSTALLATIONS AND PRELIMINARY EXPERIMENTS

(2) *Orford*

The Orford station was used essentially as supplied and installed for the Admiralty by Marconi's Wireless Telegraph Company. The aerial loops were of an approximately diamond shape, supported on a central mast 92 feet high and four corner masts 32 feet high, the horizontal span of the loops being 120 feet. Throughout all the routine observations the loops were used in the untuned condition, being connected directly to the field coils of the radio-goniometer with the midpoint of the coils earthed. The goniometer was of the tightly-coupled type and its search coil was connected to the primary of an intermediate circuit and tuned with a variable air condenser. The secondary coil of this circuit was tuned with a second condenser, leads from which were taken directly to the amplifier. In the original installation a single stage of high-frequency amplification with tuned anode and grid circuits was employed, followed by a detector valve and two or three stages of note magnification. Later this was replaced by a standard type of 7-valve high-frequency amplifying detector followed by two stages of note magnification. With these arrangements wireless bearings were usually obtainable on ship and shore transmitting stations at distances of one hundred miles with an angle of swing at the minimum down to 1°, *i.e.*, the angle at the minimum over which no change in signal strength can be observed. Although the intensity of this minimum signal strength could be reduced or even eliminated by a reduction in amplification, no gain in the accuracy to which a bearing could be observed was ever obtained thereby, and, as will be seen later, other inherent defects in the apparatus and conditions accompanying wireless direction finding in general made it unnecessary to strive after greater accuracy in these experiments.

(3) *Slough*

At the Slough station the set was also of the Marconi-Bellini-Tosi type similar to that at Orford, but of a more temporary nature, particularly in the matter of mast construction. The set was of the portable land-station type, as formerly used by the

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British Army, with triangular aerials supported on a 70-ft. central mast and a horizontal span of 200 ft. between corner posts 10 ft. high. The receiving arrangements were identical with those at Orford, with the exception that the whole hut containing the apparatus and the operator was screened with a lining of wire netting of 1-inch mesh. Measurements within such a screen have shown that the strength of field of an incoming electromagnetic wave is reduced to about 5 per cent. of its value outside the screen.[2] This resulted in the practical elimination of all direct pick-up of signal on the intermediate and amplifier circuits with the 9-valve receiver working at its highest sensitivity. It was seldom, however, that the signals from the nearer transmitting stations (*e.g.*, Teddington, distance 11·5 miles) were inaudible at the minimum position of the goniometer, and an angle of swing of about 1° was necessary in the taking of bearings. This was evidently due to capacity coupling between portions of the apparatus within the receiving hut, but as an instrumental accuracy of 1° is all that has been aimed at throughout the whole of this investigation, it was not considered expedient at the time to try and improve the apparatus beyond this stage. That the apparatus did satisfy the above limits of accuracy is confirmed by the fact that at Slough under favourable conditions the angle of swing through a silent minimum used in observing the bearing of a ship's transmitter over 200 miles away was not greater than 8°, of which the mid-point was certainly the apparent bearing to within 1°. There were of course many occasions when conditions external to the apparatus were very adverse and the above accuracy was not attained, but these must be regarded as disadvantages of wireless direction-finding as such, and must not be attributed to the particular apparatus used.

For the observations carried out on continuous wave transmissions the signals were received on the heterodyne beat-note principle, using at both Orford and Slough a screened local oscillator as previously described.[3] This type of oscillator has been found equally satisfactory on all wave-lengths employed in this investigation.

(4) *Personnel*

While the author took an active share in the observations carried out at both direction-finding stations, he was greatly assisted in these observations by Messrs. R. H. Barfield, M.Sc., S. R. Chapman, M.Sc., and M. G. Bennett, M.Sc., at Slough; and by Petty Officer R. Taylor and Telegraphists G. A. Williams and D. Connolly, at Orford.

(5) *Comparison of the Practical D.F. Systems*

In view of the change of the direction-finding system which was made as described in Section I, it was considered necessary, in order to maintain the continuity of the general investigation,

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to obtain detailed knowledge of any differences that might exist and their possible effect on the results in relation to the object of the whole research. At the time of the commencement of the investigation (1921) the knowledge possessed by various authorities on this point was somewhat hazy, and much debate had taken place on such points as, for example, the relative magnitude of "night" errors experienced on small and large coil direction finders.

In addition to the Bellini-Tosi and Robinson systems, the single rotating frame coil is a third practical system which is in use to-day for some purposes. A consideration of the simple theory of these three systems shows that there is no difference between their basic principles. In each case the reading of direction is made as the result of some portion of the system rotating about a vertical axis being set in the position in which there is a minimum, or in the ideal case, zero E.M.F. induced by the incoming waves. The methods of assembling the apparatus and detecting the above setting differ, but these do not affect the main result.

Early in 1922, typical installations of the three systems were set up at Slough for the purpose of making an experimental comparison. Later in the same year the availability of the Orford station enabled a further comparison to be made between the permanent Bellini-Tosi set already installed and a Robinson set temporarily installed for the purpose.

These experiments extended over a period of several months and the results obtained, together with a full discussion of the theory, are given in detail in a Report previously published by the Radio Research Board.[4] The conclusions drawn from the experiments verify the theoretical deduction as to the identity of the three systems in fundamental principle. Whereas each system is accompanied by its own instrumental and observational errors, the design and construction of the sets employed was such that these errors were of secondary importance in this particular investigation. Whatever distortion is produced in the field of an arriving electromagnetic wave by geographical features, etc., and whatever may be the cause of the variations experienced both by day and by night, all three systems are affected to the same degree.

It was thus satisfactorily demonstrated that this investigation could be continued on the shorter wave-lengths with the Bellini-Tosi installations in place of the Robinson sets employed in the part of the work on the longer wave-lengths. A further point settled by these preliminary experiments was that, as far as local errors and the magnitude of the variations were concerned, the site at Orford was quite comparable with those employed for the other installations. It will be seen later that its situation on the coast was fortunate in so far as it permitted the study of the accuracy of direction finding for transmission entirely oversea.

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SECTION III.—OBSERVATION PERIODS AND SUMMARY OF RESULTS

(6) *Periods of Observation*

On the completion of the experiments mentioned in the previous section, a few weeks were occupied in training the observers at Orford in the manner of attending to the requirements of this particular investigation. The regular daily observations of the apparent bearings of fixed transmitting stations were commenced on 6th November, 1922. Owing to the necessity of interspersing various special experiments among these regular observations it was not possible to maintain a constant cycle of observation periods as in the work on longer waves. In general, two daily observation periods of four hours each were worked, one of these being located in the daytime at several hours after sunrise and the other being in the evening, beginning a short time before or after sunset. These periods were maintained until 22nd December, 1923, and the observations at Orford consisted in the taking of apparent bearings of the various fixed transmitting stations in the British Isles and Western Europe operating on the wave-lengths of 450 and 600 metres. During the same period of the investigation certain experiments were carried out with ship transmitting stations in the North Sea and also with the Teddington transmitting station with aerials of various configurations. The observations made at Slough during the above period were limited to those made on three transmitting stations which sent special signals for the purpose. This was partly due to the pressure of other experimental work at Slough and partly to the fact that observation on the 450 metre wave-length was extremely difficult at times owing to the interference of harmonics from certain high-power transmitting stations.

At the latter end of 1923 a series of special experiments was begun, consisting of continuous transmissions over 24-hour periods for the purpose of investigating the effects observed at all hours of the day and night. These experiments were carried out on various wave-lengths from 450 to 2,600 metres and on continuous and interrupted continuous waves as well as on spark transmissions.

All continuous wave observations were obtained with the use of the screened oscillator at the D.F. stations.

(7) *Statement of Results*

During the whole period of working, the total number of observations obtained at Orford was 16,596, and a summary of these is given in Table 1, this table having been arrived at in the same manner as that adopted in Parts I and II of the

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Report. At Slough the number of observations collected during the same period was 6,692, and these are summarised in Table 2.

These tables are self-explanatory in the matter of wavelength, distance, true bearings, mean observed bearings and the variations obtained by both day and night. The distribution of the transmitting and observing stations utilised in this part of the investigations is shown on the gnomonic chart (Fig. 13), which is an enlargement of a section of the chart reproduced in Parts I and II of the Report.

In Tables 3 and 4 the results obtained at Orford and Slough respectively are presented in a different manner to show first the percentage of the observations which differed from the mean bearing by certain fixed amounts, and second, the proportion of cases in which no bearing could be observed on account of the extreme flatness of the signal minimum.

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TABLE 1.—*Summary of Observations taken at Orford from 13.11.22 to 29.3.24*

(1)	(2)	(3)	(4)	(5)				(6)			
Transmitting Station.	Type and wave-length.	Distance.	True bearing.	Day Observations.				Night Observations.			
				No.	Extreme variation.	Error of Mean.	Max. variation from Mean.	No.	Extreme variation.	Error of Mean.	Max. variation from Mean.
	(metres.)	(miles.)	Deg.		Deg.	Deg.	Deg.		Deg.	Deg.	Deg.
Amsterdam ..	S. 450	143	81·1	46	3·0	+ 0·6	− 1·7	9	1·0	+ 1·2	+ 0·7
Antwerp	S. 600	136	114·9	152	3·0	+ 0·5	+ 1·6	94	30·0	+ 0·9	−15·8
Berwick	S. 450	285	332·0	161	2·5	+ 0·2	+ 2·3	106	20·0	+ 0·6	+12·4
Borkum	S. 450	237	62·3	65	3·0	+ 0·3	− 1·6	127	14·0	+ 0·1	− 7·4
Boulogne	S. 450	95	178·2	519	3·5	− 0·3	+ 2·1	341	15·0	0·0	+11·8
Cherbourg ..	S. 450	220	219·9	344	5·5	− 0·2	+ 2·8	294	90·0	+ 1·0	+59·1
Cullercoats ..	S. 600	236	330·0	142	4·0	− 0·3	− 1·7	110	45·0	+ 0·5	+24·5
Dieppe	S. 450	151	188·0	206	6·0	+ 0·4	−3·4	—	—	—	—
Dunkirk	S. 450	83	154·1	294	3·0	+ 0·4	± 1·5	193	32·0	+ 0·9	+20·0
Dunkirk	S. 600	83	154·1	90	2·0	+ 0·4	± 1·0	85	15·0	+ 0·3	− 9·4
Flamborough ..	S. 450	155	334·8	331	2·5	− 0·4	− 1·4	258	45·0	− 1·5	−28·3
Flushing	S. 450	98	116·0	936	4·0	+ 0·7	+ 2·3	173	30·0	+ 0·6	−16·6
Grimsby	S. 600	123	328·0	149	4·0	− 0·5	+ 2·5	212	20·0	+ 0·8	+11·2
Havre	S. 450	188	200·0	977	5·5	− 0·6	+ 3·1	563	75·0	+ 1·5	+58·5
Havre	S. 600	188	200·0	25	3·0	− 0·6	+ 1·6	—	—	—	—
Helder	S. 450	148	65·0	544	4·0	− 0·3	− 2·2	108	11·0	+ 0·2	+ 9·8
Lizard	S. 450	327	246·2	—	—	—	—	194	25·0	+ 2·7	−13·9
Mok	S. 450	149	64·0	155	3·0	− 1·3	− 1·7	—	—	—	—
Niton	S. 600	161	230·5	81	5·5	− 4·3	− 3·2	40	20·0	− 4·6	−15·9

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TABLE 1.—*Summary of Observations taken at Orford from* 13.11.22 *to* 29.3.24—continued

(1)	(2)		(3)	(4)	(5)				(6)			
Transmitting Station.	Type and wave-length.		Distance.	True bearing.	Day Observations.				Night Observations.			
					No.	Extreme variation.	Error of Mean.	Max. variation from Mean.	No.	Extreme variation.	Error of Mean.	Max. variation from Mean.
		(metres.)	(miles.)	Deg.		Deg.	Deg.	Deg.		Deg.	Deg.	Deg.
North Foreland ..	S.	600	49·5	185·8	380	2·5	− 1·2	+ 2·4	404	15·0	− 1·2	+10·4
Ostend	S.	600	84	135·2	312	4·0	+ 0·1	+ 1·7	232	24·0	+ 0·1	+13·7
Parkeston Quay ..	S.	450	16·5	230·5	401	3·0	− 2·9	− 1·6	350	4·0	− 3·2	− 2·3
Parkeston Quay ..	S.	600	16·5	230·5	10	0·5	− 2·8	+ 0·3	10	1·0	− 2·9	− 0·6
Portland	S.	450	204	239·4	20	7·0	− 0·5	− 3·9	47	35·0	+ 7·6	−22·0
Rochefort ..	S.	600	440	195·8	—	—	—	—	106	20·0	+ 2·8	+11·4
Scheveningen ..	S.	600	117	89·2	110	6·5	− 0·5	+ 3·8	52	25·0	− 1·1	−13·1
Scheveningen ..	S.	1,800	117	89·2	139	5·5	− 0·4	− 3·8	68	35·0	− 0·3	−18·9
Teddington ..	S.	450	93	240·6	712	4·5	− 2·6	+ 2·5	551	125·0	+ 1·7	+82·7
Teddington ..	S.	500	93	240·6	72	2·5	− 3·2	− 1·4	135	13·0	− 3·1	+12·5
Teddington ..	S.	750	93	240·6	129	2·5	− 3·1	− 2·0	498	25·0	− 2·7	+12·1
Teddington ..	I.C.W.	750	93	240·6	134	2·5	− 3·0	+ 1·9	264	17·0	− 2·7	+ 9·1
Teddington ..	C.W.	750	93	240·6	147	2·5	− 3·1	+ 1·5	444	20·0	− 2·4	+11·8
Teddington ..	S.	1,000	93	240·6	34	0·2	− 2·6	+ 0·2	101	0·5	− 3·0	+ 0·4
Teddington ..	I.C.W.	1,000	93	240·6	34	1·0	− 2·6	± 0·5	76	2·2	− 3·1	+ 2·2
Teddington ..	C.W.	1,000	93	240·6	134	2·0	− 2·5	± 1·4	221	10·0	− 2·1	+ 6·5
Teddington ..	S.	1,800	93	240·6	92	2·5	− 1·8	− 1·3	120	6·0	− 2·1	− 3·5
Teddington ..	C.W.	1,800	93	240·6	196	3·5	− 1·7	+ 2·1	328	30·0	− 1·4	+15·8
Teddington ..	C.W.	2,600	93	240·6	65	2·5	− 1·4	− 1·7	123	35·0	− 2·1	+21·5
Tréguier St.Goncry	S.	450	307	224·9	15	3·5	− 2·6	− 2·3	12	13·0	+ 3·9	− 6·8
Ushant	S.	450	386	231·9	19	5·0	+ 0·2	+ 2·9	548	60·0	+ 2·0	+36·1
Wilhelmshaven ..	S.	450	293	67·8	304	4·0	− 0·6	− 2·2	323	35·0	− 1·9	+19·1

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TABLE 2.—*Summary of Observations taken at Slough from* 6-11-22 *to* 29-3-24

(1)	(2)	(3)	(4)	(5)				(6)			
Transmitting Station.	Type and wave-length.	Distance.	True bearing.	Day Observations.				Night Observations.			
				No.	Extreme variation.	Error of Mean	Max. variation from Mean.	No.	Extreme variation	Error of Mean.	Max. variation from Mean.
	(metres.)	(miles.)	Deg.		Deg.	Deg.	Deg.		Deg.	Deg.	Deg.
Orford	S. 450	100	64·0	756	6·0	+ 0·1	— 4·1	557	100·0	— 2·5	+58·5
Orford	S. 750	100	64·0	212	3·5	+ 0·6	— 2·1	630	18·0	+ 0·7	+ 9·3
Orford	S. 1,000	100	64·0	42	1·0	+ 1·3	+ 0·7	92	10·0	+ 1·2	— 5·2
Parkeston Quay ..	S. 450	84	67·5	—	—	—	—	111	6·5	— 0·4	— 3·6
Teddington ..	S. 450	11·5	116·5	590	6·5	+ 3·2	+ 3·3	520	4·0	+ 3·2	+ 2·3
Teddington ..	S. 500	11·5	116·5	133	2·0	+ 2·2	+ 1·3	137	2·2	+ 2·2	+ 1·3
Teddington ..	S. 750	11·5	116·5	159	1·3	+ 0·9	— 0·7	588	1·7	+ 1·0	— 0·9
Teddington ..	I.C.W. 750	11·5	116·5	152	1·8	+ 0·9	— 1·2	331	1·8	+ 1·1	+ 1·9
Teddington ..	C.W. 750	11·5	116·5	149	1·6	+ 0·8	— 0·9	422	2·1	+ 1·0	+ 1·1
Teddington ..	S. 1,000	11·5	116·5	40	0·7	+ 0·8	+ 0·4	94	1·3	+ 0·6	— 0·7
Teddington ..	I.C.W. 1,000	11·5	116·5	36	0·9	+ 0·5	— 0·5	72	1·2	+ 0·3	— 0·8
Teddington ..	C.W. 1,000	11·5	116·5	52	1·7	+ 0·5	+ 1·2	163	2·6	+ 0·7	+ 1·4
Teddington ..	S. 1,800	11·5	116·5	13	0·2	0·0	+ 0·2	73	1·5	— 0·1	— 0·9
Teddington ..	C.W. 1,800	11·5	116·5	112	2·6	+ 0·2	+ 1·9	266	2·6	+ 0·1	+ 1·4
Teddington ..	C.W. 2,600	11·5	116·5	66	1·5	+ 0·1	+ 0·9	124	1·6	0·0	+ 1·0

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TABLE 3.—*Showing the Percentages of Errors in Bearing and "No Minimum" Readings at Orford*

(1)	(2)	(3)		(4)						(5)	
Transmitting Station.	Type and wave-length.	Total No. of Observations.		Percentage of Bearings differing from the mean by more than						Percentage of observations missed through absence of minimum.	
				2°.		5°.		10°.	20°.		
		Day.	Night.	Day.	Night.	Day.	Night.	Night.	Night.	Day.	Night.
	(metres.)										
Amsterdam .	S. 450	46	9	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Antwerp	S. 600	152	94	0·0	19·1	0·0	10·6	0·0	0·0	0·0	24·4
Berwick	S. 450	161	106	0·1	17·0	0·0	15·1	1·9	0·0	0·0	11·3
Borkum	S. 450	65	127	0·0	23·6	0·0	3·1	0·0	0·0	0·0	9·3
Boulogne	S. 450	519	341	0·6	3·2	0·0	1·5	0·6	0·0	0·0	3·0
Cherbourg.. ..	S. 450	344	294	1·7	23·5	0·0	13·6	9·5	3·4	0·0	19·7
Cullercoats ..	S. 600	142	110	2·7	20·9	0·0	13·6	7·3	1·8	0·0	35·5
Dieppe	S. 450	206	—	1·3	—	0·0	—	—	—	0·0	—
Dunkirk	S. 450	294	193	0·0	8·8	0·0	2·0	0·9	0·0	0·0	3·6
Dunkirk	S. 600	90	85	0·0	10·4	0·0	5·7	0·0	0·0	0·0	9·3
Flamborough ..	S. 450	331	258	0·0	19·0	0·0	8·5	3·1	0·4	0·0	28·3
Flushing	S. 450	936	173	0·4	16·7	0·0	8·6	2·8	0·0	0·0	15·0
Grimsby	S. 600	149	212	2·0	17·2	0·0	6·5	1·3	0·0	0·0	21·8
Havre	S. 450	977	563	0·2	33·6	0·0	14·5	6·7	2·0	0·0	17·1
Havre	S. 600	25	—	0·0	—	0·0	—	—	—	0·0	—
Helder	S. 450	544	108	0·1	2·7	0·0	0·9	0·0	0·0	0·0	1·8

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Lizard	S.	450	94	194	0·0	33·6	0·0	18·6	6·0	0·0	0·0	29·6
Mok	S.	450	155	—	0·0	—	0·0	—	—	—	0·0	—
Niton	S.	600	81	40	12·3	9·5	0·0	7·1	2·3	0·0	0·0	26·1
North Foreland ..	S.	600	380	404	0·5	6·6	0·0	2·7	0·2	0·0	0·0	2·9
Ostend	S.	600	312	232	0·0	10·3	0·0	3·8	1·7	0·0	0·0	17·6
Parkeston Quay ..	S.	450	401	350	0·0	0·8	0·0	0·0	0·0	0·0	0·0	0·0
Parkeston Quay ..	S.	600	10	10	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Portland	S.	450	20	47	10·7	57·5	0·0	34·0	10·6	2·1	0·0	23·4
Rochefort ..	S.	450	—	108	—	14·0	—	6·5	0·9	0·0	—	11·2
Scheveningen ..	S.	600	110	52	0·9	30·7	0·0	25·0	7·6	0·0	0·0	25·0
Scheveningen ..	S.	1,800	139	68	0·0	30·0	0·0	15·7	4·2	0·0	0·0	42·6
Teddington ..	S.	450	712	551	0·1	49·6	0·0	11·8	10·0	7·3	0·0	44·2
Teddington ..	S.	500	72	135	0·0	3·0	0·0	0·7	0·7	0·0	0·0	5·2
Teddington ..	S.	750	129	498	0·0	10·6	0·0	3·8	0·6	0·0	0·0	13·6
Teddington ..	I.C.W.	750	134	264	0·0	3·8	0·0	1·1	0·0	0·0	0·0	7·6
Teddington ..	C.W.	750	147	444	0·0	3·4	0·0	1·1	0·0	0·0	0·0	30·9
Teddington ..	S.	1,000	34	101	0·0	0·0	0·0	0·0	0·0	0·0	0·0	22·8
Teddington ..	I.C.W.	1,000	34	76	0·0	0·0	0·0	0·0	0·0	0·0	0·0	7·9
Teddington ..	C.W.	1,000	134	221	0·0	3·1	0·0	0·9	0·0	0·0	2·9	61·5
Teddington ..	S.	1,800	92	120	0·0	3·3	0·0	0·0	0·0	0·0	4·3	10·0
Teddington ..	C.W.	1,800	196	328	0·0	21·0	0·0	7·6	2·1	0·0	2·5	27·5
Teddington ..	C.W.	2,600	65	123	0·0	41·5	0·0	24·4	6·5	0·0	0·0	12·2
Tréguier St. Gonery	S.	450	15	12	0·0	58·3	0·0	41·7	0·0	0·0	0·0	0·0
Ushant	S.	450	19	548	21·0	30·0	0·0	22·0	12·1	4·4	0·0	38·4
Wilhelmshaven ..	S	450	304	323	0·3	23·9	0·0	13·0	3·1	0·0	0·0	18·0

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TABLE 4.—*Showing Percentages of Errors in Bearings and "No Minimum" Readings at Slough*

(1)	(2)	(3)		(4)								(5)	
Transmitting Station.	Type and wave-length.	Total No. of Observations.		Percentage of Bearings differing from the mean by more than								Percentage of observations missed through absence of minima.	
				2°.		5°.		10°.		20°.			
		Day	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.	Day.	Night.
	(metres.)												
Orford	S. 450	756	557	1·1	54·9	0·0	19·6	0·0	12·2	0·0	4·5	0·2	25·5
Orford	S. 750	212	630	1·2	13·6	0·0	4·3	0·0	1·4	0·0	0·0	0·0	12·2
Orford	S. 1,000	42	92	0·0	9·7	0·0	1·0	0·0	0·0	0·0	0·0	0·0	0·0
Parkeston Quay ..	S. 450	—	111	—	1·8	—	0·0	—	0·0	—	0·0	—	0·0
Teddington ..	S. 450	590	520	0·3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Teddington ..	S. 500	133	137	} Greatest error experienced = 1·9°.									
Teddington ..	S. 750	159	588										
Teddington ..	I.C.W. 750	152	331										
Teddington ..	C.W. 750	149	422										
Teddington ..	S. 1,000	40	94										
Teddington ..	I.C.W. 1,000	36	72										
Teddington ..	C.W. 1,000	52	163										
Teddington ..	S. 1,800	13	73										
Teddington ..	C.W. 1,800	112	266										
Teddington ..	C.W. 2,600	66	124										

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SECTION IV.—DISCUSSION OF RESULTS—DAY OBSERVATIONS

(8) *Definition of "Day" and "Night" periods and general classification of the variations*

It will be remembered that for convenience in presenting the enormous mass of observations it has been the practice throughout the two previous Parts of the Report to classify the periods of observation as "day" and "night" periods, the day period extending from one hour after sunrise to one hour before sunset at any point on the path of transmission. Although this distinction has been found to have certain limitations, it has been used for uniformity in the summaries given in Tables 1–4 in this Part of the Report.

An inspection of Tables 1 and 2 shows that the variations experienced in the daytime at either Orford or Slough (throughout the investigation) were within the limits of 7° previously deduced as being the maximum usually experienced. In the case of this shorter wave working (450–750 metres) there is no single instance of this limit having been exceeded and in the majority of cases the limit of variation is less than 4°, which corresponds to a maximum error of observed bearing of about 2°. In the work on the longer waves discussed in the previous reports* several instances were tabulated in which the above limit of variation (viz., 7°) was exceeded in the day periods. In some cases these occurred at only one or two hours after sunrise but other cases were quoted in which the errors were experienced near midday. Although the matter is necessarily complicated by other variables in the general investigation these results appear to indicate that it is the observations on the longer wave transmissions that give rise to the largest variations in the daytime. It is very significant, for example, that subsequent observations taken at Slough on the transmissions from Leafield on a wave-length of 12,400 metres during 1924–25, have given the largest variations yet experienced for daylight working, although the range of transmission is only 48 miles. With this is to be contrasted the experience at Orford that on the shorter wave-lengths the "night" effects usually ceased either at sunrise or a short time before, although it has sometimes been noticed at Slough that the bearings of Orford began to vary at about one hour before sunset.

(9) *Permanent deviations*

Since the variations in apparent bearings are comparatively small in the daytime the errors of the mean observed bearing may be taken as the "permanent" deviations to which the direction-finding installation is subject. It has already been stated that the limiting error of the apparatus itself is of the

* See Bibliography (p. 53). Ref. 1, p. 47, and Ref. 5, p. 29.

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order of 1°, so that any permanent errors exceeding this amount must be due to some external cause. From the results at Orford summarised in Table 1 and plotted in Fig. 1, it will be seen that the error of the mean bearing just exceeds 1° in the directions of 64° and 186°, but in the region between 225° and 241° there is a negative error which is as much as 4·3° in one case, viz., on the Niton transmitting station. It is interesting to note that in this case, the Niton and Parkeston Quay transmitting stations have the same true bearing at Orford and the errors of the observed bearings were 4·3° and 2·9° respectively. This difference in the error at different distances in the same direction shows that the cause is outside the immediate vicinity of the receiving station and eliminates the possibility of the error being due to local metal work, etc., such as has been experienced at some other stations.

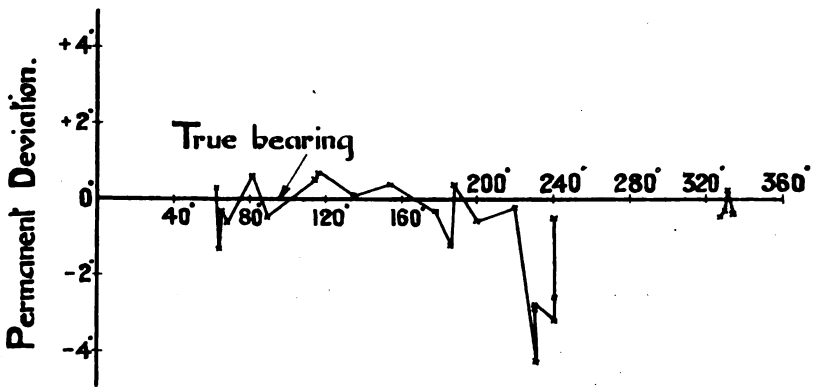

FIG. 1.—Graph of Permanent Deviations at Orford: Mean Day Errors observed from November, 1922, to March, 1924.
(Damped Waves, λ = 450 and 600 m.)

It is evident, therefore, that the cause of at least a part of the error is located between Orford and Parkeston Quay, a distance of 16·5 miles. While the larger error observed on Niton may be due to some cause between Parkeston Quay and Niton, it may also be accounted for by a refraction effect. If the waves from the Parkeston Quay station travelled along parallel to the coast line and there were a tendency for them to be refracted inwards towards the land, this would account for the sign of the error observed at Orford. If the same coast-line boundary were operative in refracting the waves from Niton to the same extent the *apparent deviation* at Orford would be increased in the manner observed.

A study of the coast line in the neighbourhood of Orford shows that down to Parkeston Quay, the tangent to the coast line makes an angle of about 220° with the true North and that the direction of 230° passes for half to two miles inland and crosses two rivers almost at right angles. This difference in the directions of the observed errors and that of the coast line may be due to

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the marshy nature of the ground near the coast, as otherwise the definite allocation of the source of the error is not at all evident. In the north-easterly direction, the tangent to the coast line is at about 65° from true North, but there are insufficient observations on transmissions from this direction to make any definite statements about the possible refraction effects.

In considering the errors experienced at Orford on the transmissions from Teddington it is to be noticed that the permanent deviation decreases as the wave-length is increased, but there is no difference observable for damped or undamped waves. Even on the longest wave employed, however, viz., 2,600 metres, the error is still appreciable, being 1·4°. A difficulty has been encountered in explaining all the above results as a coastal refraction effect on theoretical grounds, and attention has been drawn to this in note published in *Nature*.[6]

Turning now to the observations obtained at Slough in Table 2, it is seen that on the transmissions from Teddington, the error of the day mean ranged from + 3·2° on a wave-length of 450 metres decreasing to less than 0·5° on wave-lengths of 1,800 and 2,600 metres. In this case the accuracy of the installation itself was checked by disconnecting the Bellini-Tosi apparatus and placing a single frame-coil direction-finder in the same receiving hut. In a later test the Bellini-Tosi aerials were removed altogether. In each case the same error was obtained on the 450 metre transmissions from Teddington, so that it is to be concluded that the cause of the error is external to the actual installation.

Further, the whole field of some 20 acres at Slough was explored with a portable single-frame coil direction-finder, and it was found that on the wave-length of 450 metres the error on the transmissions from Teddington in positions well clear of trees varied from + 4·6° to − 4·0°, and in another position near a single tree the error reached − 6·2°. These observations were repeated in several positions after periods up to one month had elapsed, but the errors were found to be unchanged. The results given in Table 2 show that over long periods of time the variations in observed bearings were very small, indicating that there was no appreciable seasonal variation of this permanent error. In previous experiments it was found that the errors produced on a direction-finder by such local disturbances as masses of trees while quite appreciable at short distances, could be reduced to an almost negligible value at distances exceeding 100 yards. At Slough there are banks of trees on three sides of the field, but the nearest of these is some 500 feet from the Bellini-Tosi D.F. hut. A stream about 100 feet wide in parts also runs along the nearer side of the field in front of these trees and it is possible that this may have contributed to the error.

The existence of these errors confirms the previous experience of the writer that it is very difficult indeed to find a site in this

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country at which the permanent or local errors of the direction-finder are zero in every direction. This, however, is no disadvantage to the station, for provided the error is constant and is not too large, the station can be calibrated after erection and a correction curve drawn up for everyday use.

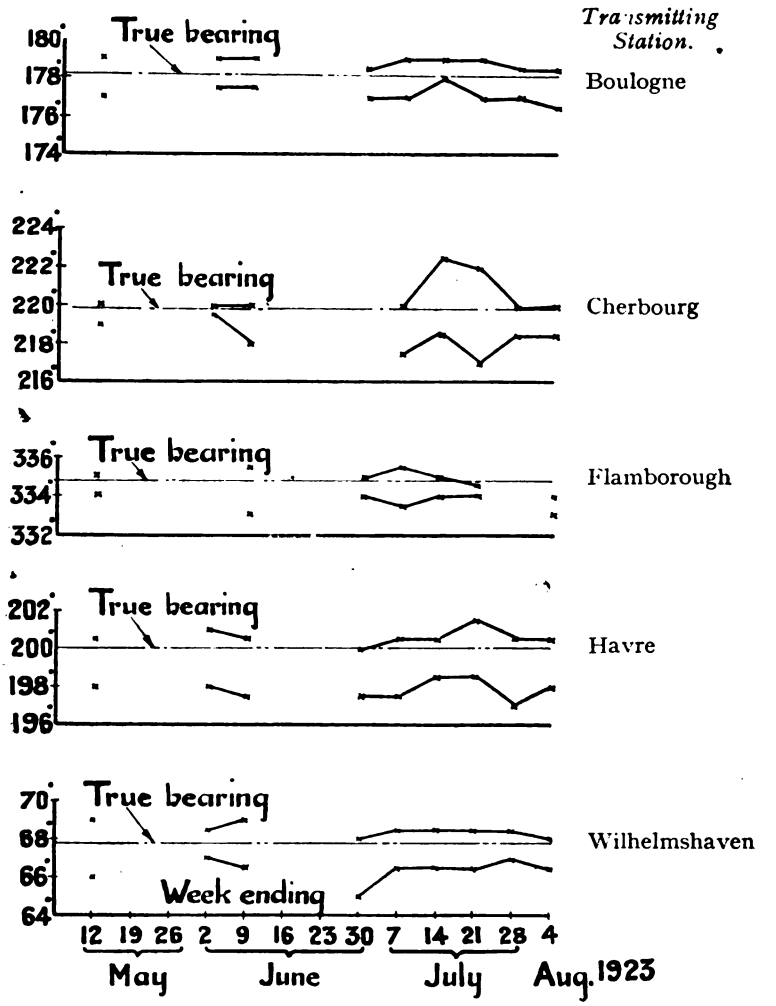

FIG. 2.—Graphs of Weekly Extreme Bearings observed at Orford between 0800 and 1200 G.M.T.
(Damped Waves, $\lambda = 450$m.)

(10) *Weekly and daily variation curves*

It has already been stated that the day variations experienced on these shorter wave-lengths were within 7°, the great majority of readings showing an extreme variation of less than 4°. In Fig. 2 is shown graphically a record of the weekly extreme

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bearings observed over the course of several weeks in the period 0800 to 1200 G.M.T. at a time of the year when sunrise occurred at from 0344 to 0430. The results are shown for the spark transmissions from five transmitting stations situated in various directions and at distances of from 95 to 293 miles from Orford.

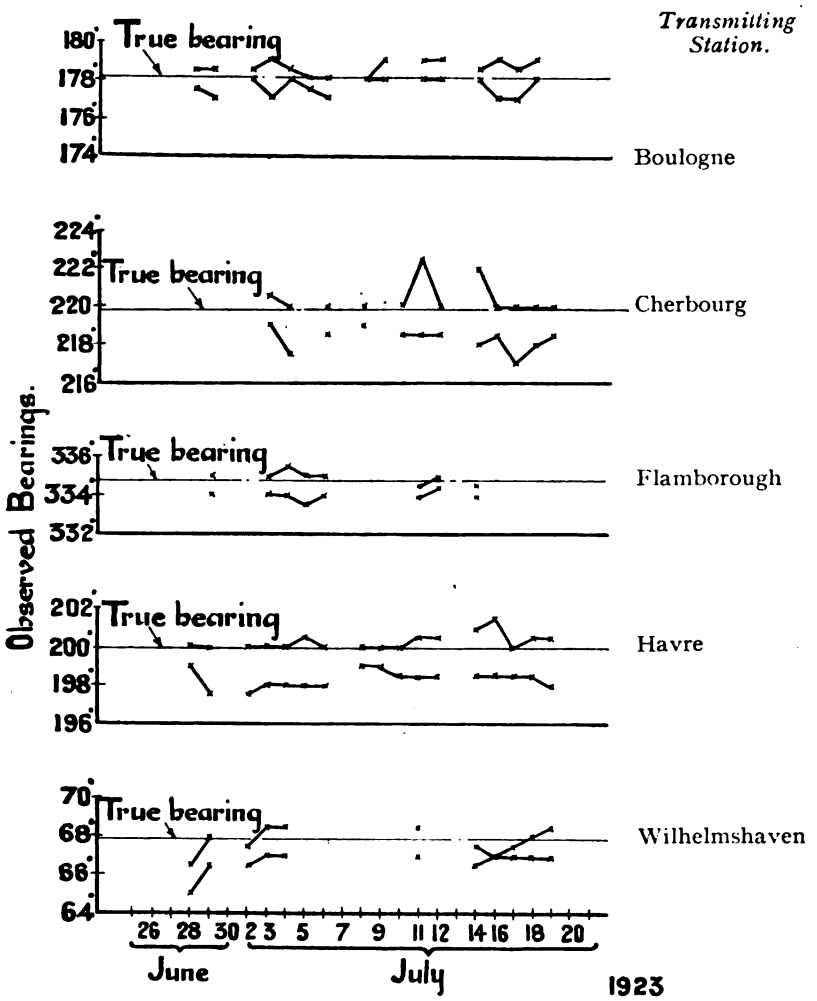

FIG. 3.—Graphs of Daily Extreme Bearings observed at Orford between 0800 and 1200 G.M.T.
(Damped Waves, $\lambda = 450$ m.)

It will be seen from this diagram that the extreme variations over a period of a week's observation is never greater than 5° and frequently it is within 2°, this latter figure corresponding to an actual error of about 1°. Further, there appears to be no striking difference between the results obtained over the shortest range (Boulogne to Orford, 95 miles) and over the longest (Wilhelmshaven to Orford, 293 miles).

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In Fig. 3 the daily extreme bearings observed on the same five transmitting stations are shown for four weeks approximately in the middle of the period of Fig. 2. In this diagram it is seen that although the variation from day to day is sometimes greater than the variation experienced on any one day, this effect is not nearly so marked as it was in the cases pointed out in Parts I and II of this Report.* This is no doubt partly due to the fact that in the present instance the observations are scattered over a four-hour daily period, whereas on the longer wave-length the period of observations of any one station was rarely greater than one hour and often only half an hour.

The present diagrams confirm the conclusions previously arrived at in the work on longer waves, that at ranges of about 100 miles and upwards definite variations in apparent bearings occur which, while being only a few degrees in magnitude, are definitely greater than the limits of error of the direction-finding instrument. Further, it is seen from the present diagram that there is no obvious similarity in the variations experienced on several transmitting stations.

SECTION V.—DISCUSSION OF RESULTS—NIGHT OBSERVATIONS

(11) *Systematic error of the mean bearings at night*

From the summaries of the readings given in Tables 1 and 2 it will be seen that in the majority of cases the errors of the day and night mean bearings differ by less than one degree. Among the remaining instances there appears to be a systematic error of the night bearings of from one to two degrees in the case of Cherbourg, Flamborough, Grimsby, Ushant and Wilhelmshaven as observed at Orford. The observations taken on Orford at Slough show a systematic night error of $-2{\cdot}6°$ on a wave-length of 450 metres; while much more marked examples are to be found in the case of the observations at Orford on the transmissions from Portland, Teddington and Tréguier St. Gonery, when the systematic night errors were $+8{\cdot}1°$, $+4{\cdot}3°$ and $+6{\cdot}4°$ respectively, all on the 450 metre wave.

(12) *Magnitude of the night variations*

At the Orford station the largest variations experienced in this portion of the investigation were 125° and 90° on the transmissions from Teddington (450 m.) and Cherbourg respectively. At Slough the observations on Orford's 450 metre transmissions gave a variation of 100°. The maximum errors in observed bearings in the above cases were $82{\cdot}7°$, $59{\cdot}1°$ and $58{\cdot}5°$ respectively. As has been pointed out in previous parts of this Report,

* See Bibliography (p. 53). Ref. 1, p. 56, and Ref. 5, p. 43.

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however, these large errors are of comparatively rare occurrence, and Tables 3 and 4 show that in the above cases the proportion of readings giving errors exceeding 20° is only from 3·4 to 7·3 per cent. It is to be observed that the largest errors at Orford and Slough occurred for ranges of transmission of 93 to 100 miles overland, and that the cases in which a greater range of transmission was employed up to nearly 400 miles, the errors experienced while still very appreciable, were less than those detailed above. This conclusion confirms those arrived at in the previous parts of the Report to the effect that at ranges of the order of 100 miles overland, the errors experienced are as large or larger than those recorded for longer ranges of transmission up to the limit of about 1,500 miles covered by this investigation.

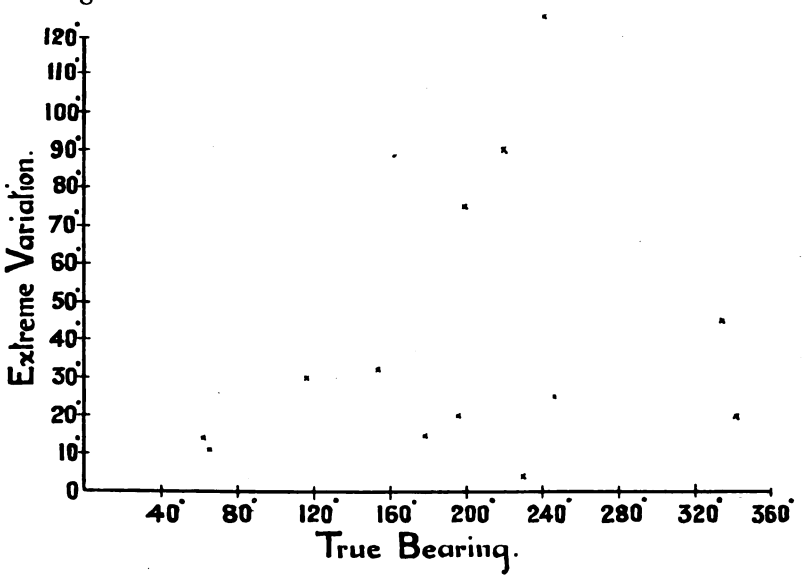

FIG. 4.—Showing Relation of Extent of Variation against True Bearings at Orford for Transmitting Stations over 50 miles distant.

(Damped Waves, $\lambda = 450$ m.)

(13) *Relation of variations with the direction of transmission*

Fig. 4 shows a graphical representation of the extreme variations of bearings observed at Orford on all transmitting stations at distances exceeding 50 miles. The results plotted were confined to those made on transmissions on a wave-length of 450 metres and to those cases in which more than 50 observations were made. Although there is just a suggestion that the variations are of a less order of magnitude in the neighbourhood 160° to 190° than in the directions on either side of this sector, the number of results available on this graph is considered to be too small from which to draw any more definite conclusions.*

* *Cf.* Bibliography (p. 53). Ref. 1, p. 64, and Ref. 5, p. 51.

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(14) *Dependence of variations upon wave-length*

In the last section it was seen that on the same wave-length of 450 metres the extreme variations recorded varied considerably for the different transmitting stations. This fact must be borne in mind in considering the manner in which the amplitude of variation depends upon the wave-length employed. To provide some information on this point the observations on Scheveningen at Orford were specially made on the two wave-lengths of 600 and 1,800 metres employed by this transmitting station. Although Table 1 shows that the extreme variation on the shorter wave was 25° and on the longer wave it was 35° it is seen from Table 3 that the proportion of bearings more than 5° in error is 25 per cent. on 600 m. as against 15·7 per cent. on 1,800 m. Somewhat similar remarks will be found to apply to the observations recorded on the two wave-lengths of 450 and 600 metres employed by the Dunkirk transmitting station.

The difficulty of drawing a definite conclusion on this point is complicated not only by the very erratic nature of the variations but also by the occurrence of the phenomenon of "broad minimum." In column (5) of Table 3 is recorded the proportion of the number of occasions upon which the signal minimum on the radiogoniometer was so broad that a definite reading was impossible. While it is difficult to avoid some personal error in recording the cases in which the minimum is too blurred for a definite reading, it was considered that when a signal was easily audible at the minimum position and showed no apparent change in intensity over an arc of 40° to 80° the condition was one of "no minimum." It is partly owing to the indefinite nature of this effect that the results recorded in Table 3 are so erratic.

Returning to the question of the effect of wave-length upon the variations, many special transmissions were made from Teddington on various wave-lengths between 450 and 2,600 metres and the resulting observations at Orford are included in the summaries in Tables 1 and 3.

Ignoring for the moment the effect of wave damping, which will be discussed in a later section, it is seen that the results are very erratic. From Table 1 it would appear that the variations are abnormally high on 450 metres and low on 1,000 metres. Yet Table 3 shows that the proportion of errors exceeding 5° is highest on 2,600 metres with 450 metres as the next highest, whereas in considering the errors over 10° the position is reversed. Furthermore the proportion of "no minimum" readings on 1,000 metres is the highest recorded in Table 3, while those made on 450 metres are the next highest in the table. In some cases it appears that the results are dependent upon the number of observations made and thus upon the limitations of the experiments, but this rule is by no means universal in its application. The observations made at Slough on the transmissions from Orford on the wave-lengths of 450-1,000 metres, appear to show that both the variations and the frequency of occurrence of

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broad minima are greater on 450 metres than on the longer waves. With such erratic results it can only be concluded that no definite relation has been established between the extreme variations and the wave-length employed, over the range 450-2,600 metres. From the data analysed in Parts I and II of this Report [1 and 5] the conclusion can be extended to cover the whole wave-length range employed so far in this investigation, viz., 450-9,000 metres.

There are, however, two personal impressions which the author would like to record as a result of experience in operating direction-finders over this range of wave-lengths. It will be recalled that on the longer waves the Robinson system was employed, in which the operation of the switch was equivalent to swinging a coil over an arc of 30° through the minimum position. Although, therefore, with this system it was difficult to explore the exact nature of the signal minimum, it was only on very rare occasions that this was so broad that a bearing observation was impossible. On the shorter waves, however, and with the use of systems working directly on the signal minimum the results show that the occurrence of this very broad minimum is comparatively frequent and in some cases about half the observations resulted in no bearing being observed on account of the absence of any detectable minimum in the signal obtained for different settings of the goniometer. In the daytime the minimum was always quite sharp with the consequent high accuracy in bearings recorded. The change from day to night conditions was generally brought about by an increase in the signal strength with the receiving goniometer in the minimum position, until the signal strength was apparently uniform for all settings of the goniometer and at least equal to the daytime strength for the maximum position. This indicates that at night the resultant magnetic field of the waves arriving at the receiver was circularly polarised in a horizontal plane, as distinct from the plane polarisation which prevails in the daytime.

The second impression to be recorded is that the maximum rate at which the apparent bearings move at night is very much greater on the short than on the longer wave-lengths. In Part I of the Report it was mentioned that the maximum rate of variation of bearings was about 37·5° in ten minutes, whereas on the wave-length of 450 metres variations of about 40° per minute have been noted at both Orford and Slough. If the mean of the upper wave-length range be taken as 4,500 metres, it would appear as a very approximate rule that the maximum rate of variation of bearing is inversely proportional to the wave-length used. It may be possible to obtain some further data on this point in the further observations which are being made with an extension of wave-length range.

(15) *Weekly and daily variation curves*

In Figs. 5 and 6 are plotted the weekly and daily extreme bearings observed during the night periods for the same days

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and for the same five transmitting stations whose day readings were represented in Figs. 2 and 3. In accordance with the practice adopted throughout the Report, the scale of observed bearings is made five times as large for the day as for the night

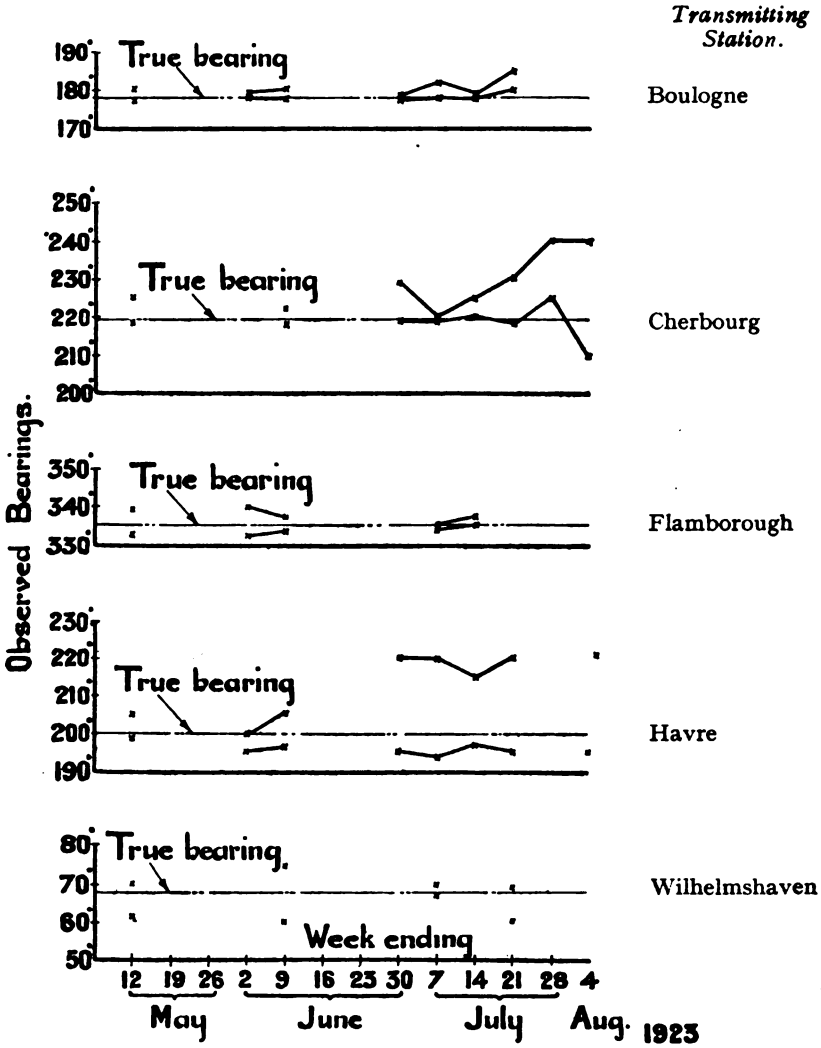

FIG. 5.—Graphs of Weekly Extreme Bearings observed at Orford between 2000 and 2400 G.M.T.
(Damped Waves, $\lambda = 450$ m.)

readings. The time of observations in the periods under discussion were 2000 to 2400, while the time of sunset varied from 1937 to 2018. It will thus be seen that during a nightly observation period of four hours beginning at about sunset an extreme variation ranging up to 25° was obtained and that with a few

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exceptions these variations occur every night, with a resulting weekly extreme variation ranging up to 30°. In view of the suggested relation between the magnitude of the variations and the direction of transmission which has been discussed in this Report,* it is interesting to point out that in Figs. 5 and 6 the

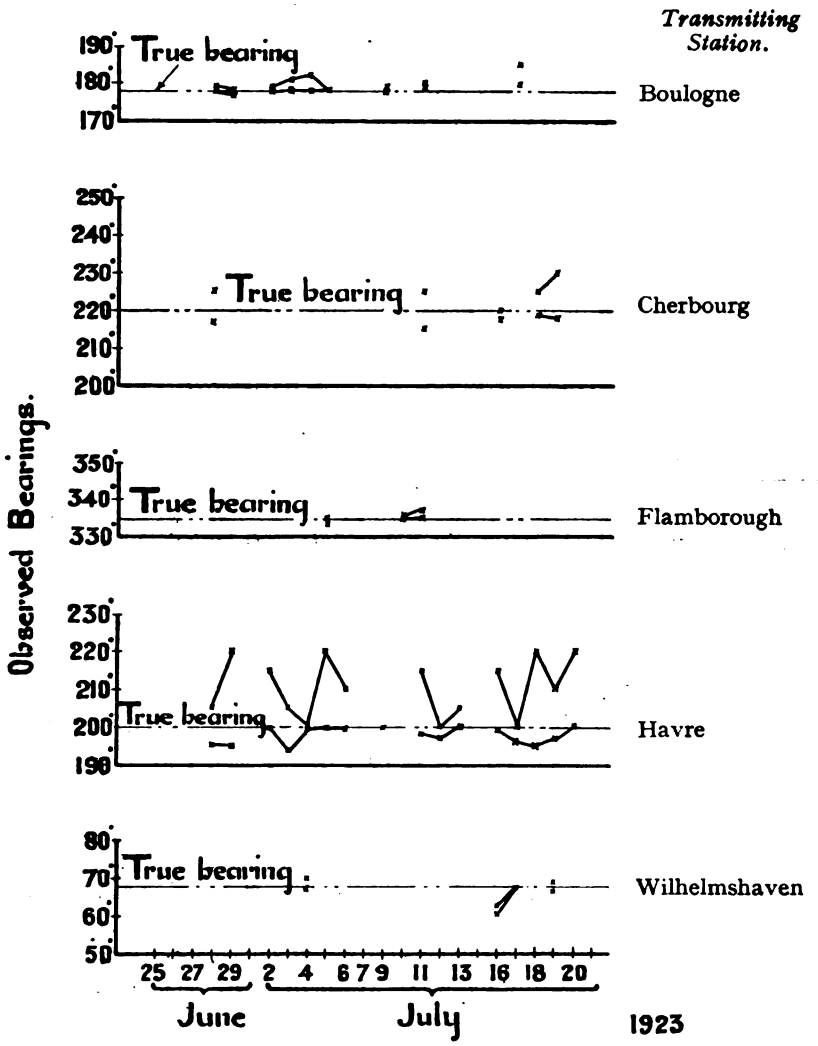

FIG. 6.—Graphs of Daily Extreme Bearings observed at Orford between 2000 and 2400 G.M.T.
(Damped Waves, $\lambda = 450$ m.)

transmitting stations of Boulogne and Flamborough, situated in directions of 178° and 335° respectively from due North, gave noticeably smaller variations than the other three transmitting stations whose directions widely differ from the N.–S. line.

* See p. 19.

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SECTION V.—RESULTS OF SPECIAL EXPERIMENTS CARRIED OUT DURING THE INVESTIGATION

(16) *Graphs of individual observations obtained over 24-hour periods*

Towards the latter end of the period of the investigation with which this part of the Report deals, a number of experiments were arranged in which observations were carried out continuously over 24-hour periods, during which special transmissions were made by the Orford and Teddington transmitting stations. These experiments were directed towards the solution of a number of problems simultaneously, such as a comparison of the variations encountered with damped and undamped waves both on the same and on different wave-lengths. The various special points investigated are discussed in the appropriate sections of this present Report, but it is convenient to give the general results here with the aid of graphs shown in Figs. 7–10.

The tests were usually made by making a cycle of four sets of transmissions every ten minutes throughout the whole 24 hours, three transmissions being made by Teddington, and the fourth by Orford. As is noted on the diagrams, the Teddington transmissions comprised a suitable combination of wave-lengths and types of waves, while Orford's transmissions were confined to the use of damped waves on either 450, 750 or 1,000 metres.

A first glance at the diagrams gives the impression that during these experiments the variations experienced were of comparatively rare occurrence. This is, however, due to the fact previously noticed that during the night periods a large number of observations were rendered impracticable owing to the extreme broadness of the signal minimum. The frequency of occurrence of this phase of the night effects experienced in direction-finding is indicated in the diagrams and definite figures were given in Tables 3 and 4.

Fig. 7 represents the results of a test carried out on the 750 metre wave-length in December, 1923, and shows, first, the manner in which the variable errors are well confined between the limits of sunset and sunrise, and second, the similarity in the variations experienced with either spark, interrupted continuous wave or continuous wave transmission. The results of a similar test carried out in January, 1924, are shown in Fig. 8, from which it appears the night errors were very small at this particular time, although the usual broad minimum effect was occasionally experienced. The permanent error in the bearing of Teddington as observed at Orford is shown up in these diagrams and has already been discussed.

In Figs. 9 and 10 are shown the results of two tests made in March, 1924, during which continuous waves of 1,800 and 2,600 metres length were compared with damped waves of 450 metres. In other cases not illustrated, damped and undamped waves of 750 metres wave-length were compared with the damped

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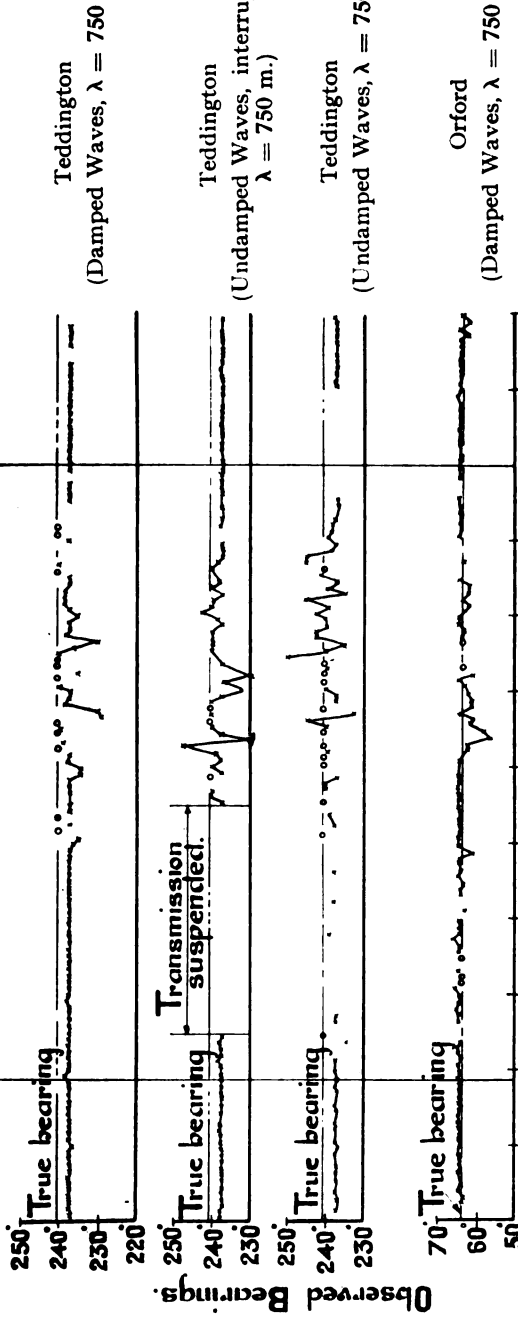

FIG. 7.—Graphs of Observed Bearings of Teddington at Orford, and of Orford at Slough over a 24-hour Period, 13th to 14th December, 1923.

× indicates definite bearing observation.
o indicates minimum too broad for bearing observation.

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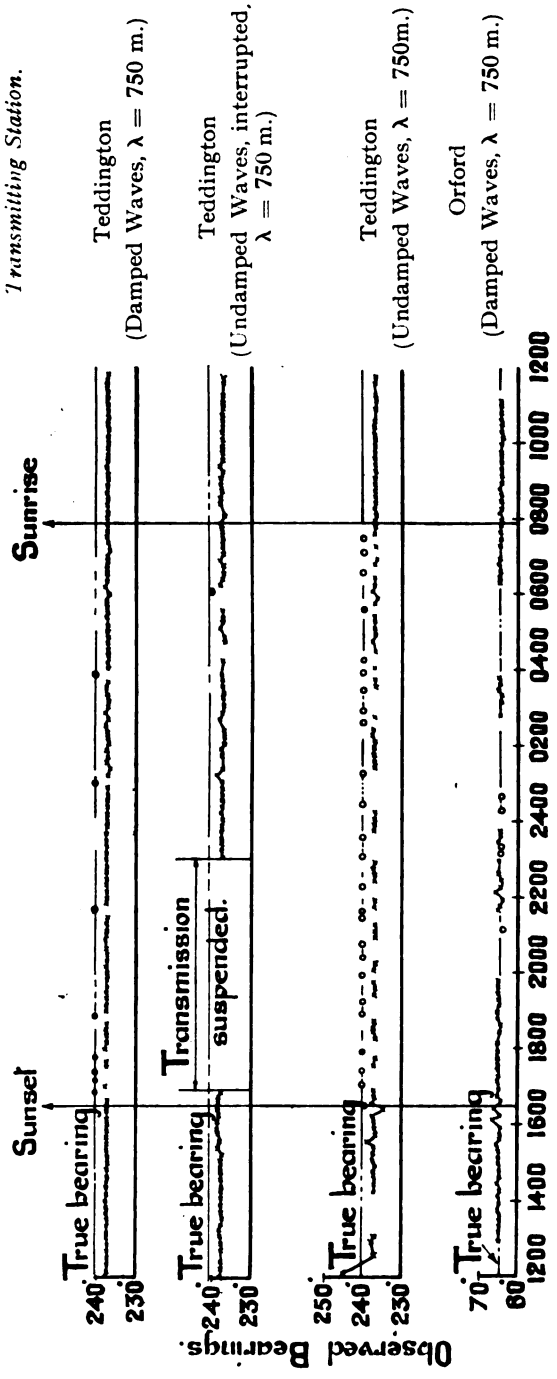

FIG. 8.—Graphs of Observed Bearings of Teddington at Orford, and of Orford at Slough over a 24-hour Period, 24th to 25th January, 1924.
× indicates definite bearing observation.
o indicates minimum too broad for bearing observation.

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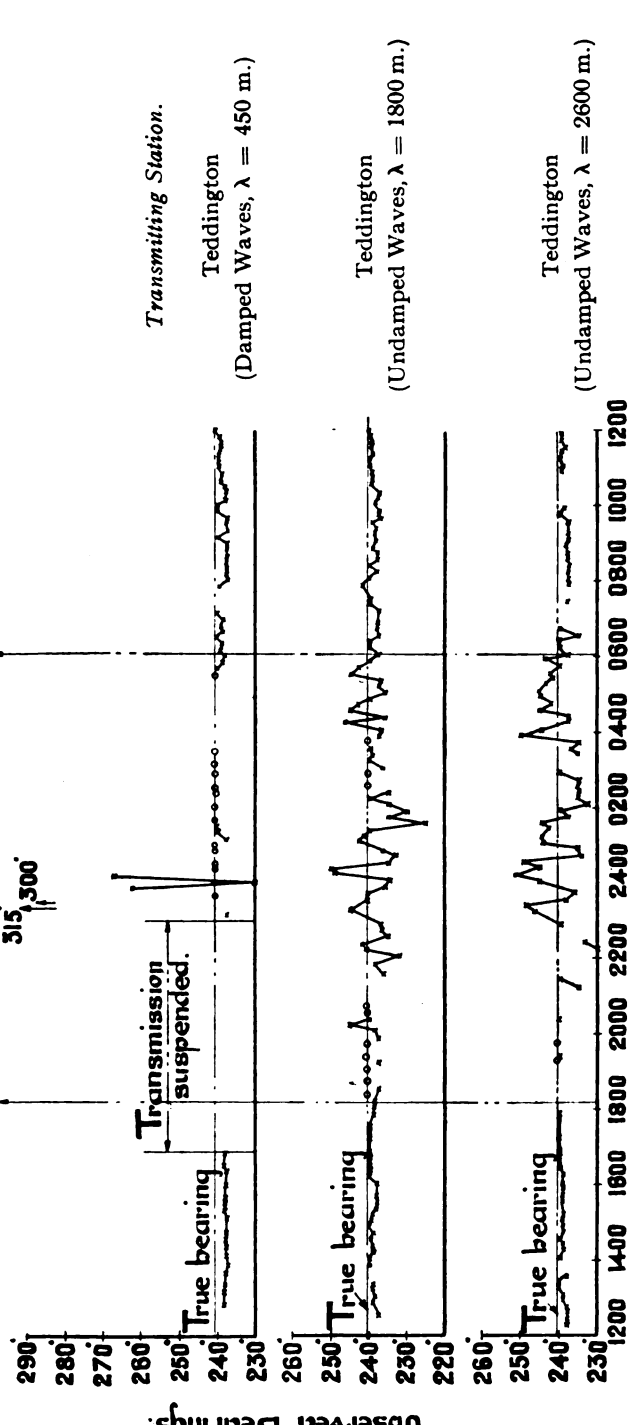

FIG. 9.—Graphs of Observed Bearings of Teddington at Orford over a 24-hour period, 20th to 21st March, 1924.

× indicates definite bearing observation.
o indicates minimum too broad for bearing observation.

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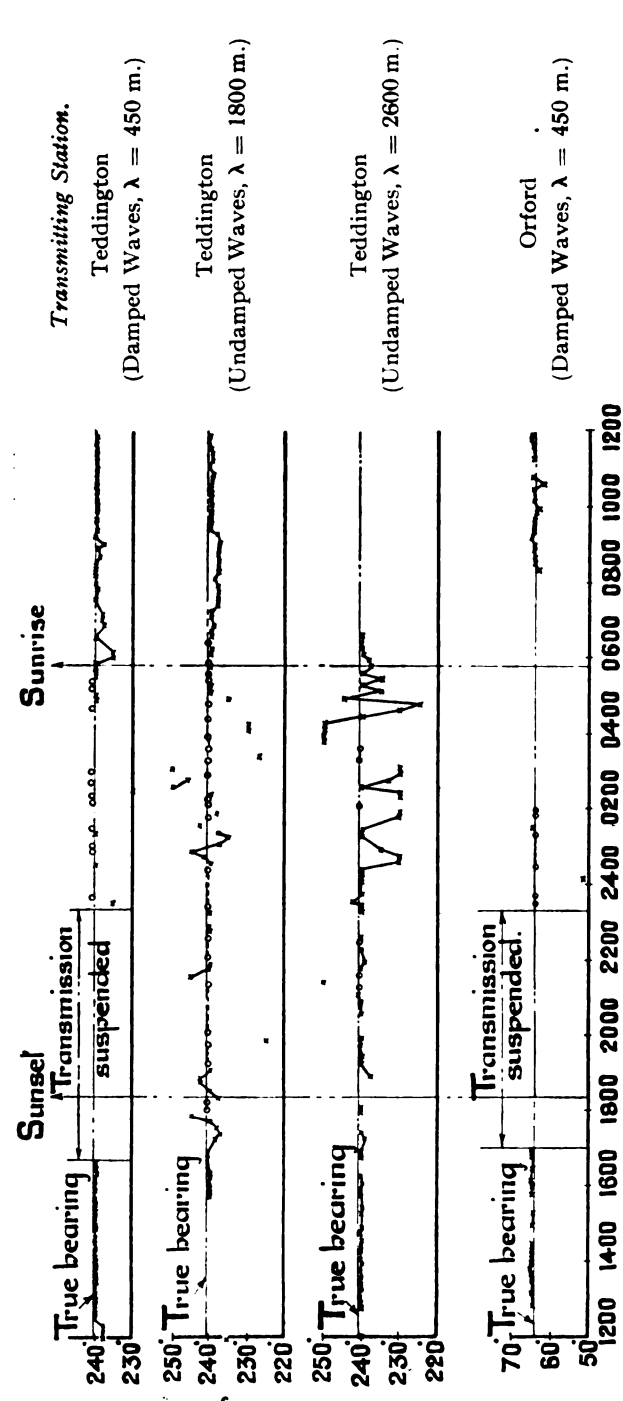

FIG. 10.—Graphs of Observed Bearings of Teddington at Orford, and of Orford at Slough over a 24-hour Period, 27th to 28th March, 1924.

× indicates definite bearing observation.
o indicates minimum too broad for bearing observation.

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waves of 450 metres. The chief features to be noted here are that while, on the whole, the variations are of the same order on the different wave-lengths there is a tendency for the occurrence of blurred minima to be more frequent on 450 metres than on the other waves, which, as mentioned above and elsewhere, is not attributable to the damped waves used on the latter wave-length.

From all these diagrams it is seen that the night effects are strictly confined to the period between about one hour before sunset and one after sunrise in a similar manner to the behaviour previously observed on the longer waves in Parts I and II of the Report.

During the carrying out of these experiments the observed bearings of Teddington at Slough remained remarkably constant on each individual wave-length and no effect whatever was distinguishable as due to the different types of waves employed. With the exception of the permanent deviations already discussed under Section IV, 9 (p. 13), the vast majority of the readings differed from their respective means by less than 1°, and as already shown in Tables 2 and 4, in all but a negligible percentage of the readings the difference was less than 2°.

(17) *Comparison of results oversea and land*

(*a*) *Preliminary*

In the previous portions of this investigation carried out on the long waves, the majority of the transmitting stations were situated inland, and although three of the D.F. stations were located on the coast, it was the general rule that transmission was overland for at least a portion of the total path. Under such conditions it was found that when the range of transmission was greater than 30 miles, the apparent bearings observed varied over small amplitudes during the day and much larger amplitudes at night. With the commencement of operation of the Orford Station it was proposed to take the opportunity of studying D.F. conditions when the propagation was entirely oversea for varying distances. The co-operation of the authorities of the Great Eastern Railway Company made this possible by permitting the transmission of special signals by the Company's ships passing between England and the Continent. Experiments were commenced in October, 1922, and continued at various periods until their conclusion in November, 1923. In a paper[7] published elsewhere a descriptive summary of the results and experience obtained during this part of the main investigation was given, the matter being considered particularly from the point of view of the application of direction-finding at shore stations to the navigation of ships at sea.

(*b*) *Duration and Procedure of Experiments*

The first tests made on special transmissions from the boats of the Great Eastern Railway Company were carried out during

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the two weeks commencing 9th October, 1922. On a somewhat extended scale the experiments were resumed on 12th February, 1923, and continued intermittently until 15th November, 1923, at which date the experiments were concluded, after a total period of nearly fourteen weeks nightly observations had been worked. Figs. 11 and 12 show portions of a chart illustrating the routes taken by the ships between Parkeston Quay and the Continent, and the stations at Orford, Slough and Teddington.

The general procedure adopted during this work was briefly as follows :—As each of the various ships approached one of the light vessels or light buoys on its route to or from the Continent, the wireless operator warned by the navigation officer made a preliminary call to Orford. After receiving the reply from Orford, the ship's operator sent a special code signal for a period of about a minute and a half to enable the observers at Orford and Slough to make simultaneous determination of the wireless bearings of the ship. Direct and reciprocal readings on the goniometer scale were always taken and the mean of these (with the appropriate 180° correction) was taken as the observed bearing. At the time of sending of the special signal the ship's navigation officer recorded the ship's position, as estimated by distance and compass bearing from the light vessel. The above procedure was repeated for each ship on passing each light vessel or buoy, the code signal used in the transmission being sufficient for identification purposes in the recorded readings. At the conclusion of each week of the experiments the log sheets from the ships and from the D.F. stations were sent in independently to the National Physical Laboratory. With the unavoidable exception of the writer, the D.F. observers were purposely kept uninformed as to the positions of the ships, the operators of which also knew nothing of the conditions or results at the D.F. stations. These precautions, together with the prohibition of any communications between the operators on ship and shore, permitted the reception of absolutely unbiassed results.

The approximate time of the useful part of the passage of the various boats was from 2200 to 0430 G.M.T. for the outward-bound boats from Parkeston Quay to Antwerp and the Hook of Holland, and from 0030 to 0530 G.M.T. for inward-bound boats on the same routes.

As only one observer per night was available at each of the two D.F. stations, a continuous watch of more than six hours was not considered advisable. In the majority of the experiments, the period of working was from 2245 to 0400 G.M.T., use being made of that portion of the passage of the two outward and the two inward-bound boats which fell within this period. In practically each of these cases darkness prevailed throughout the whole test. During the summer, however, when the schedule times of the boats were altered to British Summer Time, the periods worked were 0100 to 0700 G.M.T. to observe the effect of sunrise and subsequent daylight.

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In addition to the above special signals sent from the ships transmissions were made at intervals during each observation period by the Great Eastern Railway Company's station at Parkeston Quay, the National Physical Laboratory's station at Teddington, and for the use of the Slough observer only, by the Orford station. This arrangement was made to enable a comparison to be made between the D.F. observations taken on the ship stations, with those taken during the same periods on land stations over distances of the same order.

In entering the readings on the observation sheets for both ship and shore stations, the observer recorded his opinion as to the reliability of the observation as judged from the nature of the signal minima. As previously noted, bearings on signals of adequate strength could be observed with an angle of swing of about 2°, and under favourable conditions this angle was not greater than 8° in observing at Slough on signals transmitted by a ship on the far side of the North Sea over a distance of nearly 200 miles. In many cases, however, this angle was necessarily much larger, due to the adverse conditions experienced, the most prominent of these being interference, flat minima and wandering minima.

The two latter were very frequent in some portions of the test and were characterised first by a signal audible all through the minimum, the strength of which gave no detectable change over an angle sometimes amounting to 90°; and secondly, by a drift of the minimum at a varying rate round the goniometer scale.

Although no really hard-and-fast rule can be given to observers to determine the reliability of observations, it is in general not considered that accurate bearings can be obtained when the angle of swing is greater than about 20°.

When observing on the ship transmitters at Orford the signal minima were always steady, excepting the drift due to the actual motion of the ship, when transmitting at short ranges. Although the minima in some cases had become appreciably flattened, and the observations were accordingly marked "unreliable," the results showed that the corresponding error in bearing was usually quite small.

(*c*) *Discussion of the results obtained*

During the whole period of these experiments the total number of observations taken on the ship's transmissions was 996, and an additional 3,444 observations were made on the transmissions from the land stations. A summary of all the results obtained and a detailed discussion thereof is given in the paper already referred to and only a brief statement of the conclusions obtained will be given here.

Table 5 gives a summary of all the observations made (at Orford and Slough) in the form of numbers and percentages of bearings with varying errors. Of the observations taken at Orford it will be seen that over 87 per cent. of the bearings are

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TABLE 5.—*Summary of all Observations made at Orford and Slough on Transmissions from G.E.R. Boats*

Error in Bearing.	Orford.		Slough.	
	Number.	Per cent.	Number.	Per cent.
Up to 1° ..	247	43·6	86	22·5
,, 2° ..	395	69·7	172	45·0
,, 3° ..	495	87·3	237	62·0
,, 5° ..	555	98·0	295	77·0
,, 10° ..	567	100·0	347	90·6

correct within 3°, the maximum error being 9°·3. The errors recorded at Slough are much greater than those at Orford and range up to 34°, while in 46 cases no bearing was obtainable on the ships at Slough on account of the absence of any detectable minimum of signal strength for the whole rotation of the goniometer search coil. Whereas at Orford a negligible proportion of the results are more than 5° in error, at Slough 23 per cent. are in error by this amount, and in 9·4 per cent. of cases the error exceeds 10°.

Table 6 gives the results obtained at Orford in the form of the numbers and percentages of the observed bearings whose errors are not greater than 2° for the different positions of the ship transmitters. These figures show generally that as the distance from the ship to Orford increases, the proportion of the results correct within 2° increases from about 45 per cent. to 90 per cent.

TABLE 6.—*Showing numbers and percentages of all bearings up to 2° in error, observed at Orford on ships at the various positions*

Position of Ship.	Approximate distance from Orford.	Errors in Bearing, 0°–2°.		Error in ship's position corresponding to 2° error in bearing.
		Number.	Per cent.	
	(miles)			(miles)
Shipwash ..	11·0	24	44·5	0·36
Cork	12·5	76	68·5	0·45
Sunk	16·0	27	49·0	0·56
Longsand ..	21·5	18	58·0	0·71
O. Gabbard ..	24·0	31	61·0	0·80
Galloper	30·5	64	82·0	1·00
N. Hinder ..	58·0	72	80·0	1·67
Wielingen ..	87·0	66	85·5	2·86
Maas	102·0	18	90·0	3·34
All positions ..	Various	396	70·0	—

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The relation is not a strict one in view of the high percentage accuracy obtained at the Cork position, and it is also to be pointed out that systematic errors of about 2° had been observed on boats when at the Shipwash and Sunk positions and corrections for these would greatly increase the percentages corresponding to the Shipwash and Sunk positions. The general increase in accuracy with increase in distance, however, suggests that some at least of the errors arise from some uncertainty of the knowledge of the ships' positions from which the true bearings are obtained.

In the last column of Table 6 are given the values of the error in the position, which correspond to a 2° error in bearings at Orford, and from these it is seen that for the positions closer than the Galloper it is necessary that the ship's position recorded be correct within one mile, and that at the Shipwash L.V. an accuracy of one-third of a mile is required. Now whereas under favourable conditions the estimated position is well within such a limit of accuracy, various circumstances arose in these experiments which might considerably increase the difference between actual and recorded positions. Among these circumstances are the prevalence of bad weather, mist, etc., which made a visual estimate of distance uncertain, and some unavoidable delay between the determination of the position and the transmission of the special wireless signal, while on some occasions interference prompted the observer at Orford to request a repeat signal from a fresh position of the ship which was not always corrected. It should also be noted that all observations were made while the ships were travelling at a speed in the neighbourhood of 20 knots, and that at a short range such as from the Shipwash, the motion of the ship during the transmission of the one and a half minute signal corresponds to a change in bearing at Orford of about 3°. This drift in the observed bearing was very noticeable, but the mean of the direct and reciprocal readings gives the only average value which can be used. This point is one which must frequently arise in the commercial use of direction-finding at short distances and is partially avoidable by decreasing the duration of the transmission and observing the bearings as quickly as possible, in the manner adopted in the special tests to be described later.

The general result of this analysis of the observations taken at the Orford station is therefore that under ordinary working conditions at sea wireless bearings can be obtained on ships at distances up to about 80–100 miles across open sea to an accuracy such that over 80 per cent. are correct within 2°, and that the frequency of occurrence of an error of more than 5° is such as to be negligible for practical working. What may be termed "incipient night effect" was evidenced at the longer ranges by flatness of minima, but no error of any magnitude due to this cause has been experienced.

At the Slough station the night effects were very much more prominent in the way of extreme flatness of minima and large

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TABLE 7.—*Summary of all Observations taken after Sunrise, at Slough, during experiments with G.E.R. Boats*

Error in bearing.	Reliable.		Unreliable.
	Number.	Per cent.	Number.
Up to 1°	23	33·3 } 76·8	—
1° to 2°	30	43·5 }	1
2° to 3°	14	20·3	—
Over 3°	2	2·9	2
Total	69	100·0	3

errors in observed bearings ranging up to nearly 34°. As demonstrating the accuracy which is obtainable in the absence of these night conditions, Table 7 gives a summary of all the observations taken on the ships at various times after sunrise. Nearly 77 per cent. of the reliable readings were correct within 2°, these being taken at distances ranging from 89 up to 191 miles. At the Maas light vessel at a distance of 191 miles from Slough, eight of the nine readings obtained were within 2°, the remaining reading being — 2·2° in error.

(*d*) *Transmissions from Land Stations*

In Table 8 is given a summary of the results obtained during these experiments in making D.F. observations on the three land stations employed for the purpose. The spark transmitting set at each station was employed and the wave-length of 450 metres was used throughout. As previously mentioned, the majority of the work was done at night, but the day readings tabulated are those taken in the portions of the observation periods which were more than one hour after sunrise. The results given are typical of those which may be observed at any direction-finding station when working at comparable distances and when the path of transmission is partly or wholly overland.

Where the distance is comparatively short, as in the case of Parkeston Quay to Orford, and Teddington to Slough, no difference by day or night is found in the accuracies of the observed bearings nor in the sharpness of the minimum signal readings. In the absence of any interference the angle of swing at the minimum was from 1° to 2°, and the midposition could usually be determined to about 0·2°. Under such conditions the observed readings had a maximum amplitude of about 3°, corresponding to a maximum difference from the mean of about 1·7°, and Table 8 also shows that in less than 2 per cent. of cases is the difference greater than 1°. In the two cases quoted there is a permanent deviation of the mean observed bearing from the true value of over 3°, these errors and their possible causes having been discussed previously in this part of the Report.

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TABLE 8.—*Summary of Observations made on Fixed Shore Stations during Experiments with Ships*

Transmitting station.	Observing station.	Distance of transmission.	Period of observations.	Observations possible.	Observations obtained.	Mean bearing.	Error of mean.	Extreme variation.	Max. variation from mean.	Cause of missed observations.			Variations from mean.		
										Absence of minimum.	Wandering bearing.	Interference.	Up to 1°.	Up to 2°.	Up to 5°.
		(miles)				(deg.)	(deg.)	(deg.)	(deg.)	(per cent.)	(per cent.)	(per cent.)	(per cent.)	(per cent.)	(per cent.)
Parkeston Quay	Orford	16·5	Day	105	105	227·5	− 3·0	3·0	± 1·5	—	—	—	98·0	100·0	—
			Night	386	386	227·4	− 3·1	3·0	+ 1·6	—	—	—	99·0	100·0	—
Teddington..	Orford	93	Day	161	153	237·3	− 3·3	4·0	+ 2·2	0·7	—	4·0	83·0	95·0	—
			Night..	672	163	238·0	− 2·6	47·0	+24·0	54·5	15·0	6·5	13·7	18·3	21·5
Orford ..	Slough	98	Day ..	166	155	63·8	− 1·5	4·5	− 2·8	—	—	6·6	60·2	92·2	93·5
			Night..	647	369	61·0	− 4·3	65·0	−36·0	26·5	7·7	8·8	3·6	10·7	37·7
Parkeston Quay	Slough	83	Day ..	105	105	67·5	+ 0·3	2·5	− 1·5	—	—	—	93·5	100·0	—
			Night..	400	353	67·1	− 0·1	23·0	−12·6	7·7	1·0	3·0	64·8	75·7	82·2
Teddington..	Slough	11·5	Day ..	167	167	120·1	+ 3·6	1·6	+ 0·9	—	—	—	100·0	99·7	—
			Night..	635	633	120·3	+ 3·8	2·6	+ 1·7	—	—	0·3	99·0	—	—

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Reverting to the results given in Table 8, it will be noted that for the greater ranges of transmissions (83 to 98 miles) the observations obtained by night differ greatly from those obtained by day in several respects. In the first case, whereas practically all the readings obtained in the daytime were marked reliable, only a few being missed, due to interference, a large proportion of the night readings obtained were classed as unreliable, due principally to the flatness of the minima. Secondly, the variations in observed bearings at night were very much more noticeable than in the day; the extreme magnitude of these being 65° by night as against 4·5° by day. Thirdly, in a large proportion of cases bearing observations were impossible at night, due either to the extreme flatness of the minimum signal or the rapidity with which the apparent bearing was wandering about. For example, of the transmissions from Teddington observed at Orford, in 69·5 per cent. of cases no definite indication of the bearing could be obtained during the period of the special signal (1½ minutes), whereas perfectly good bearings were being obtained on the same transmissions at Slough. At the latter station bearing observations on Orford were impossible in 34·2 per cent. of cases, due to the prevailing night effect conditions. These phenomena were experienced nearly every night and the extreme cases were quite frequently encountered in which no variation in signal strength was experienced for a complete rotation of the goniometer search coil, this signal at night often being much stronger than that observable in the daytime in the maximum position.

When it was realised that the accuracy of the results obtained in transmission from the ships was of a high order, several weeks' observations were carried out at Orford on the coast transmitting stations, which are on an open sea path from the D.F. station. The majority of these observations were made on the 600 metre wave, and a summary of the results is included in Table 9. Reference to the chart on p. 52 will show the positions of the various stations relative to Orford.

Although North Foreland is the nearest of these stations at a distance of 49·5 miles, the path of the waves to Orford scarcely comes within the scope of the term " open sea," since it involves considerable tracts of sandbanks at the mouth of the Thames. For practical purposes the transmission is therefore overland for a portion of the distance and as a result it is seen that a maximum error of 10·4° occurred although 90·5 per cent. of the readings were within the 2° limit. The nearest of the remaining stations with an open sea path to Orford are Dunkirk and Ostend at 83 and 84 miles respectively. For these two stations the maximum errors recorded at night were 20° and 13·7°, while the proportions of the readings which gave less than 2° error in bearing were 84·8 per cent. and 69·5 per cent. for the two transmitting stations. As the distance of the oversea transmission is increased the magnitude and frequency of the character-

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TABLE 9.—*Summary of Observations made at Orford on Fixed Coast Stations during experiments with Ships*

Transmitting station.	λ Metres.	Distance of transmission.	Period of observations.	Observations possible.	Observations obtained.	Mean bearing.	Error of mean.	Extreme variation.	Max. variation from mean.	Observations missed through absence of minima.	Variations from mean.		
											Up to 1°.	Up to 2°.	Up to 5°.
		(miles)				(deg.)	(deg.)	(deg.)	(deg.)	per cent.	per cent.	per cent.	per cent.
N. Foreland ..	600	49·5	Morning	380	380	184·6	− 1·2	5·5	− 3·1	0·0	94·0	99·7	100·0
			Evening	402	392	184·6	− 1·2	15·0	+10·4	2·5	84·5	87·6	93·5
Dunkirk ..	450	83	Day ..	294	294	154·5	+ 0·4	3·0	± 1·5	0·0	99·4	100·0	—
			Night ..	193	186	155·0	+ 0·9	32·0	+20·0	3·6	84·5	90·2	94·8
Dunkirk ..	600	83	Morning	90	90	154·5	+ 0·4	2·0	± 1·0	0·0	100·0	—	—
			Evening	86	77	154·4	+ 0·3	15·0	− 9·4	9·3	80·3	84·8	88·3
Ostend ..	600	84	Morning	313	312	135·3	+ 0·1	4·0	+ 1·7	0·3	96·8	99·7	99·7
			Evening	236	196	135·3	+ 0·2	24·0	+13·7	16·9	68·3	69·5	76·3
Flushing ..	450	98	Day ..	936	936	116·7	+ 0·7	4·0	+ 2·3	0·0	93·0	99·7	100·0
			Night ..	173	147	116·6	+ 0·6	30·0	−16·6	17·7	59·8	83·7	98·7
Scheveningen	600	117	Day ..	110	110	88·7	− 0·5	6·5	+ 3·8	0·0	91·0	99·0	100·0
			Night ..	82	39	88·1	− 1·2	25·0	−13·1	25·0	21·1	34·6	48·1

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istic night effects are also increased. For example, on the 600-metre wave, Scheveningen at a distance of 117 miles gave only 34·6 per cent. of the readings with an error of less than 2°, while in 25 per cent. of the cases the signal minima were too flat for an observation to be made.

These results taken on the fixed coast transmitting stations therefore support the preliminary conclusions drawn above from experiments with ship transmitters, that for moderate distances of transmission oversea up to about 80 miles, the large majority of wireless bearings are accurate at all times to within 2°.

It is further evident that for greater ranges oversea the proportion of accurate readings diminishes at night to such an extent that at distances greater than 100 miles the night effects of errors and bad minima are so pronounced that the wireless bearings observed would be of little use for navigation purposes at such times. By day, however, the accuracy is unimpaired for ranges of transmission up to two or three hundred miles, whether oversea or overland.

(e) Results of Final Tests

With the benefit of the experience gained during the experiments above described, two special tests at the Orford station were arranged in October and November, 1923, in which every effort was made to reduce to a minimum all the errors which had previously been encountered or suspected. At the invitation of the Great Eastern Railway Company, the writer was privileged to be on board the two ships participating in the test to supervise the transmission of the special signals and observe the conditions under which ships' positions were determined. Two tests were carried out on return journeys to the Hook of Holland and Antwerp respectively. During each of these tests, after the first communication had been established with Orford, all preliminary wireless procedure was dispensed with, and as the ship passed abreast of each of the selected marks *en route* the special signal was transmitted for a total period of one minute only. No repeat signals were permitted and it is a testimony to the efficiency of the Orford Station to state that in no single instance was an observation missed on these special signals transmitted without any warning whatever. By adopting this procedure it was possible to reduce to the minimum all delay and consequent error due to the motion of the ship.

On the journey to and from the Hook of Holland, the selected buoys and light vessels from which transmissions were made were passed, with one exception, within 200 yards and several of them within 100 feet. Conditions were arranged as far as possible so that the ship passed abreast of the mark at about half-way through the special signal, but accurate time records were kept to enable corrections to be made for the drift of the ship during the transmissions; the speed of the ship in this test being 18 knots in the open sea.

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The first observation was taken during the preliminary communication, while the ship was alongside Parkeston Quay, and as in the case of observations on the land station at the Quay a correction of + 3° is necessary to make the observed bearing agree with the true value. A similar correction was also made for the observations taken on the ship at two buoys between the Quay and the mouth of the river.

In the table of results, No. 10 (page 40), a correction of — 2° has also been applied to the bearings taken when the ship was passing the Shipwash Buoy and Lightvessel, to compensate for the systematic error, already referred to on p. 33. The weather conditions during the test varied from hazy on the outward journey to fine and clear, with rain at intervals, on the inward journey.

The results given in Table 10 show that, assuming the corrections made as above are justifiable, the maximum error of the wireless bearings throughout the test is 1·1°, all the remainder being correct to within 1°. It is notable also that, although in the case of the longest ranges employed the readings were marked "unreliable" on account of the flatness of the signal minima and consequent large angles of swing which were necessary to determine the bearings, the resulting errors are all less than 1°.

The test made on the journey to Antwerp was under very similar conditions. A strong wind prevailed throughout, and although fine weather was experienced, the sky was overcast on the outward journey. An average speed of a little over 17 knots was maintained by the ship. The route in this case did not lie so close to the lighted marks, the distance of which varied up to 3 miles. This distance was, however, obtained by the "four-point bearing" method, using the ship's magnetic compass, and the distance run being recorded on the ship's log. The results obtained are given in Table 11, and as before, corrections have been applied at the D.F. station for the sector 220°–240°, and also to the charted bearing taken on the Sunk Light vessel. It would appear from the table that this correction, applied for the latter case, is scarcely sufficient since the resulting errors are two of the five which exceed 1°. The only errors greater than 2° were obtained at the N. Hinder Lightship, but as this was passed at a distance of 3 miles, the estimate of the ship's position may not have been sufficiently accurate.

The reading on the outward journey is notable since the D.F. bearing was particularly sharp, the minimum being located with a swing of only 1·5° from its mid position. In this test also, five readings were experienced with flat minima and marked unreliable, but the resulting errors are again small, three of the five being correct within 1°.

A summary of the combined results obtained in these two tests is given in Table 12 (p. 42), which shows the high percentage

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TABLE 10.—*Results obtained in special D.F. test made at Orford with s.s. St. Denis on a return journey to Hook of Holland 15–17th October, 1923*

Date.	Time.	Position of ship.	From Orford.			Error.	Remarks.
			Distance.	True bearing.	Observed bearing.		
Outward Journey—			(miles)	(deg.)	(deg.)	(deg.)	
15.10.23 ..	2202	Parkeston Quay	16·5	230·5	230·3*	− 0 3	W/T D.F. readings very good. Angles of swing less than 5°.
15.10.23 ..	2254	Guard Buoy	15·0	228·8	228·0*	− 0·8	
15.10.23 ..	2303	Beach End B.	15·0	222·4	222·3*	− 0·1	
15.10.23 ..	2317	Cork L.V.	12·5	210·6	211·0	+ 0·4	
16.10.23 ..	0000	Shipwash B.	6·5	143·8†	143·7	+ 0·9	
16.10.23 ..	0020	Shipwash L.V.	11·0	117·0†	116·5	− 0·5	
16.10.23 ..	0102	O. Gabbard L.V.	24·0	101·2	102·3	+ 1·1	
16.10.23 ..	0509	Maas L.V...	102·0	92·0	92·5	+ 0·5	Unreliable readings; minima flat and angles of swing 35° to 90°.
16.10.23 ..	0528	Gas B.	108·0	91·8	92·5	+ 0·7	
Inward Journey—							
16.10.23 ..	2313	Hook of Holland ..	113·0	93·1	94·0	+ 0·9	Unreliable readings; minima flat and angles of swing 25° to 60°.
16.10.23 ..	2338	Gas B.	108·0	91·8	92·5	+ 0·7	
16.10.23 ..	2357	Mass L.V.	102·0	92·0	92·5	+ 0·5	
17.10.23 ..	0344	O. Gabbard L.V. ..	24·0	108·1	108·3	+ 0·2	
17.10.23 ..	0424	Shipwash L.V.	11·0	116·0†	116·5	+ 0·5	All readings reliable and very good. Angles of swing less than 5°.
17.10.23 ..	0442	Shipwash B.	6·5	145·9†	145·5	− 0·4	
17.10.23 ..	0519	Cork L.V.	12·5	211·2	211·7	+ 0·5	
17.10.23 ..	0532	Beach End B.	15·0	221·7	222·0*	+ 0·3	
17.10.23 ..	0543	Guard B.	15·0	228·8	228·0*	− 0·8	
17.10.23 ..	0604	Parkeston Quay	16·5	230·5	231·0*	+ 0·5	

* Wireless bearings corrected by +3·0° to compensate for D.F. station error.

† Charted bearing corrected by +2·0° to compensate for D.F. station suspected error in positions of Shipwash Buoy and Light vessel.

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TABLE 11.—*Results obtained in special D.F. test made at Orford with s.s. Malines on a return journey to Antwerp, 12th–15th November, 1923*

Date.	Time.	Position of ship.	From Orford.			Error.	Remarks.
			Distance.	True bearing.	Observed bearing.		
Outward Journey—			(miles)	(deg.)	(deg.)	(deg.)	
12.11.23 ..	2220	Parkeston Quay	16·5	230·5	230·3*	− 0·2	Reliable D.F. readings; angles of swing less than 5°.
12.11.23 ..	2311	Cork L.V.	12·5	211·0	211·0	0·0	
12.11.23 ..	2345	Sunk L.V.	16·0	171·8†	173·0	+ 1·2	
13.11.23 ..	0003	Longsand L.V.	21·5	160·8	160·3	− 0·5	
13.11.23 ..	0039	Galloper L.V.	30·5	145·3	146·3	+ 1·0	Flat minima; angle of swing, 20°.
13.11.23 ..	0209	N. Hinder L.V.	58·0	127·5	124·3	− 3·2	Reliable reading; angle of swing, 3°.
13.11.23 ..	0319	Wandelaar L.V.	81·0	126·5	126·3	− 0·2	Unreliable; angle of swing, 20°
13.11.23 ..	0339	Wielingen B.	87·0	123·9	124·3	+ 0·4	Reliable; angles of swing, 6° to 15°.
13.11.23 ..	0426	Flushing	101·0	117·3	117·5	+ 0·2	
Inward Journey—							
14.11.23 ..	2315	Flushing	101·0	117·3	117·5	+ 0·2	Reliable; angle of swing, 7°.
15.11.23 ..	0010	Wielingen B.	87·0	123·3	123·7	+ 0·4	Unreliable reading; angles of swing, 25° to 40°.
15.11.23 ..	0039	Wandelaar L.V.	81·0	126·3	125·0	− 1·3	
15.11.23 ..	0145	N. Hinder L.V.	58·0	129·9	132·5	+ 2·6	
15.11.23 ..	0310	Galloper L.V.	30·5	145·3	145·5	+ 0·2	
15.11.23 ..	0348	Longsand L.V.	21·5	160·8	160·0	− 0·8	Reliable readings; angles of swing, less than 5°.
15.11.23 ..	0403	Sunk L.V...	16·0	171·4†	172·7	+ 1·3	
15.11.23 ..	0434	Cork L.V.	12·5	211·0	210·7	− 0·3	
15.11.23 ..	0455	Guard B.	15·0	228·8	228·0*	− 0·8	
15.11.23 ..	0512	Parkeston Quay	16·5	230·5	231·0*	+ 0·5	

* Wireless bearings corrected by +3·0° to compensate for D.F. station error

† Charted bearing corrected by +2·0° to compensate for suspected error in position of Sunk Light vessel.

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accuracy of the wireless bearings obtained. It is to be observed that throughout these tests the usual phenomena of " wandering bearings " and " no detectable minimum " were experienced at Orford on the transmissions from Teddington, so that the wireless D.F. conditions on these nights cannot be described as in any way unusual.

TABLE 12.—*Summary of results obtained in the two special tests with ships' transmissions in October and November*, 1923

Error in bearing.	Reliable observations.		Unreliable observations.		All observations.	
	No.	Per cent.	No.	Per cent.	No.	Per cent.
Up to 1° ..	24	85·7	8	80·0	32	84·2
,, 2° ..	27	95·4	9	90·0	36	94·7
,, 3° ..	27	95·4	10	100·0	37	97·4
,, 4° ..	28	100·0	—	—	38	100·0

(f) Conclusions

The accuracy to which wireless direction-finding can be carried out has both a practical and scientific interest. On the practical side those concerned with the application of direction-finding to marine navigation are anxious to know the most serious errors that are likely to be met with under various conditions and to know also what precautions are necessary to avoid these errors or reduce them to the minimum. On the other hand, there are those who, while not being directly interested in the practical side of direction-finding, look to the results of its investigation for the shedding of light upon the more general problem of the propagation of electromagnetic waves over the earth's surface. It is thought that the results of the experiments here described will afford some tangible information of interest to both parties.

The general deductions to be drawn from this investigation may here be given as a conclusion to the present section. With radio direction-finding apparatus of the type now obtainable for commercial use at a land station, the limiting accuracy of observed bearings which is obtainable by highly skilled operators under the most favourable conditions is of the order of 1°. To attain such an accuracy careful attention must be given to various details of the apparatus, and the installation must be calibrated somewhat elaborately for any local deviations. When operating over long periods of time the above accuracy is only maintained throughout both day and night for short ranges of the order of 10–16 miles. At greater distances up to about 200 miles, the limit of error increases to about 2° and this can

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be maintained for daylight working only. When the transmission is entirely overland for distances of the order of 83 to 98 miles, the evidence supplied in Table 8 is sufficient to show that such direction-finding is practically useless for any navigational purpose at nights, when most serious errors are of very frequent occurrence. In some cases the observing operator is able to judge as to whether the bearing is a good one or not, but this judgment does not appear to be sufficiently reliable to be used as a working rule. The experience of the author and other experimenters has shown that these variations and night effects are encountered at ranges down to about 30 miles overland.

When, however, the transmission is entirely oversea so as to be well clear of any land effects, the accuracy of observed bearings is maintained within the limit of 2° for night as well as for day working at distances which approach 60 miles; and even up to 100 miles, over 90 per cent. of bearings are correct within 2°, the limiting error under ordinary working conditions being about 4°. Such an accuracy is probably good enough for most navigational purposes. The effects of an error of even this magnitude can be very much reduced by taking several observations at intervals of, say, five or ten minutes. The above distances probably indicate the extreme ranges for accurate working for, as previously noted in the paper, many of the observed readings showed distinct signs of the approach of night errors as commonly experienced in transmission overland. Also the results given in Table 9 for transmission from a land station entirely oversea show the errors which may be incurred at distances in excess of 80 miles.

For the successful application of direction-finding to the navigation of ships it is therefore preferable that a clear sea path exists between the ship and the D.F. stations, in which case reliability is secured at distances of 60 to 100 miles. Should the path of transmission include more than about 16 miles of land, variable errors are likely to be encountered at night, in addition to the ordinary coastal error at all times. From the results given above, it will be evident that the taking of check bearings on a fixed station transmitting overland affords no indication whatever as to the reliability of bearings observed on a ship at sea at the same periods. What is usually required by the navigator of a ship at sea, however, is not a line bearing, but a position fix; but assuming the same error in wireless bearings to be obtainable by two or more D.F. stations, the accuracy to which such a position fix can be given by simultaneous observations is a matter of mere geometry. The extension of the present investigation to cover the operation of two or more D.F. stations *on the coast* was not considered sufficiently useful to justify the expense involved.

The result of the investigation which is of more scientific interest is that the minimum range of transmission for the

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occurrence of the well-known phenomena of night effects on closed loop direction-finders is about three times as great overseas as that overland. The exact ratio is possibly dependent upon the relative conductivities of the sea and land respectively, and the resulting attenuation accompanying the propagation of the electromagnetic waves.

(18) *Effect of the shape of the transmitting aerial on variations of apparent bearings*

To account for the variations in the apparent bearings which have formed the subject of the investigation described in these Reports, a theory was put forward by Eckersley[8] in 1920 which ascribed the errors to the reception of an indirect wave arriving at the receiver in a downward direction, the polarisation of this wave being such that it possessed a horizontal component of magnetic field in the plane of propagation, the corresponding electric force being horizontal. The direct wave travels horizontally along the earth's surface and arrives at the receiver polarised with the electric field practically vertical, and the magnetic field horizontal and at right angles to the plane of propagation. This theory derives some support from the observed experimental facts that the arrival of an abnormally polarised wave in a direction which is not horizontal will in general give rise to an error in the bearing at a ground direction-finding station. For example, errors in the apparent bearings of aircraft transmitters are commonly experienced when the angle of elevation at the ground D.F. is appreciable; *e.g.*, at an elevation of 18° the error may be as much as 60° for certain orientations of the transmitting aerial. Further, it has been shown from a study of the radiation from such aircraft transmitting aerials, that a type of bent L antenna which contains an unbalanced component of horizontal current will, in free space, emit waves which are so polarised that the electric force has components parallel to both the horizontal and the vertical portions of the transmitting aerial. In view of this possible explanation of the variations it was considered important to determine whether it was necessary for the waves to be polarised in a suitable manner at the transmitter in order to give rise to variations in bearings at a distant direction-finding station.

Now the stations whose transmissions have been utilised for the observations recorded in Parts I–II of the present Report comprised nearly forty commercial stations scattered over Great Britain and Western Europe.

With a view to ascertaining the effect, if any, of the dimensions and shape of the transmitting aerials, details of these were sought from the authorities responsible for the respective stations whose transmissions had been used for observation purposes. Up to the time of writing, however, details have only been received for the British stations. A graphical representation of the variations in bearing experienced on those stations which

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have an inverted L aerial with a long horizontal portion pointing in a known direction, showed that there was no definite relation between the direction of the receiving station relative to the transmitting aerial and the variations in bearings experienced, whereas such an aerial should not radiate in its own plane a wave suitably polarised to cause variations in bearings. In other cases, where the transmitting aerial is known to have no unbalanced horizontal portions, very appreciable variations have been experienced during the periods of observation. Although the effects are necessarily somewhat difficult to establish with certainty, owing to the large number of other variables, such as distance, geographical features, etc., which accompanied these observations, the only general conclusion which can be drawn is that no evidence is supplied that the errors or variations in observed bearings are in any way dependent upon the radiation of abnormally polarised waves from the transmitter. These observations were made on wave-lengths from 2 to 10 km. employing both damped and undamped waves.

Originating from a suggestion made by Professor G. W. O. Howe in 1920, it was decided that an experimental transmitting station should be set up at which the conformation of the aerial could be altered and its effect upon a directional receiver at a distance could be studied. Various considerations precluded the possibility of the erection of an aerial of sufficient vertical and horizontal dimensions for the carrying out of the experiments at long wave-lengths, and 450 metres was ultimately selected as the wave-length, employing damped waves from a spark transmitter. From the other experiments already described it was known that the effects observed would not be fundamentally different on any other wave-lengths within wide limits, nor would they differ with the use of undamped waves.

The aerial employed for these experiments was erected at the National Physical Laboratory and arrangements were made for the erection of four different aerials, viz., a plain vertical cage, a symmetrical T aerial, and inverted L aerials with the free end pointing first to the East and then to the West. Each aerial was erected in turn, and daily transmissions were made for two successive weeks employing the spark transmitter at Teddington on a constant wave-length of 450 metres. During this period, observations of the apparent bearings of the transmitter were made at Orford and Slough, using the installations already described. The complete investigation, including all the control experiments from both Teddington and Orford, occupied three months. As the experiments and the results obtained have been described in detail elsewhere[9], only a summary of the conclusions reached will be given here.

The general conclusion to be drawn from this experimental investigation is that all attempts made to arrange the conformation of the transmitting aerial so as to prevent the emission of radiation polarised in such a manner that the electric field is

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horizontal and magnetic field vertical, have been unsuccessful in materially reducing the occurrence of night effects encountered at a distant direction-finding station. If, therefore, Eckersley's theory of night errors is correct, the abnormally polarised component of the downcoming waves would appear to be due either to the reflecting layer not always being horizontal or to the effect of the earth's magnetic field in causing a rotation of the plane of polarisation of the waves on reflection at the upper ionised layer[10].

It should be remarked that the intensity of this reflected wave must quite often be greater than that of the direct wave, for it was frequently observed during the tests that the strength of signal in the maximum position of the search coil by day was less than the strength at night when the coil was perpendicular to this.

(19) *Effect of wave-damping upon the variations*

In Part II of this Report[6] a brief comparison of the errors experienced on the longer wave transmissions using both damped and undamped waves was made and the conclusion was reached that no detectable difference was experienced. This conclusion must be qualified by the assumption that all necessary precautions had been taken to eliminate any possible instrumental error due to the use of a local oscillator for heterodyne purposes. In the present Report it has already been stated that one of the objects of the carrying out of the special experiments over 24-hour periods was the comparison of the effects obtained with damped and undamped waves.

On the shorter wave-lengths on which direction-finding is employed for navigation purposes, this point is one of vital importance, since the progress of wireless communication generally demands the employment of the spark system to the smallest possible extent, and it is thus obviously desirable that any beacon transmitting stations set up for the use of ship's direction-finders should if possible operate on undamped or interrupted undamped waves. In a paper recently published[11] the author has collected all the available information on the subject. A résumé of the previously published data showed that there had hitherto been little opportunity of making any comparison between the relative effects of damped and undamped waves upon the errors and variations experienced on radio direction-finders. The somewhat contradictory ideas which had existed in the early days of direction-finding were most probably due to the fact that previous comparisons were made between damped waves of length less than 1·5 km. transmitted over short or medium ranges and undamped waves of great length (greater than 5·0 km.) at comparatively long ranges. The only results extracted from the present investigation for the discussion of this matter were those taken under the nearest approach to the

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ideal conditions that seemed practicable. These ideal conditions being that both the damped and undamped waves should be identical in wave-length, and transmitted successively from the same aerial with as short an intervening period as possible. From such careful systematic observations carried out on various wave-lengths from 750 to 6,000 metres, it was concluded that the liability of wireless direction-finding to the type of errors known as " night effect " is equally great with damped and undamped waves. The observations were mostly taken on transmissions over comparatively great distances overland, but since it has already been shown that when the path of transmission is entirely oversea and free from land and coastline effects, direction-finding with damped waves is accurate enough for most navigation purposes at distances up to 80–100 miles, it is to be inferred that equal reliability would be obtained with undamped waves.

(20) *Effect of local atmospheric conditions, rain, fog, etc.*

Throughout the whole three and a half years that this investigation has continued no relation has been evident between the variations observed and the main weather conditions which would ordinarily be noticeable to the observer. On several occasions throughout the investigation attempts have been made to correlate the variations in apparent bearings with meteorological records. One of the main difficulties in this connection is the comparatively wide separation of the meteorological recording stations, and the unsuitable location of the majority of these with respect to the wireless transmitting and receiving stations. Also in the case where these stations are separated by several hundred miles, the weather conditions may vary considerably along the path of transmission at any instant. Such attempts as have been made have so far led to no useful results. In a similar manner an inspection of records of the intensity of the earth's magnetic field does not appear to be likely to yield any assistance, particularly since the variations of this quantity are of the same order by day and night.

From the point of view of navigation an important factor to be noted is any effect of fog on direction-finding, since it is chiefly during foggy weather that the majority of direction-finding stations are called into action. On several occasions the author has taken particular notice of the existence of fog at times when direction-finding observations were in progress with a negative result. On one occasion in particular the fog was spread over the British Isles and a large portion of Western Europe, but the directional variations showed nothing beyond the usual day and night effects.

It would appear from this experiment, and also the fact that cloud and overcast weather have no effect, that the cause of the variations is not to be found in the effect of the sun on the lower portions of the earth's atmosphere.

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SECTION VII.—CONCLUSIONS

(21) *Concluding discussion on the Investigation*

This Report brings to a close the discussion of the results obtained in the investigation on the variations of apparent wireless bearings as it was originally planned, whereby simultaneous observations should be carried out at two or more direction-finding stations. The results considered above were obtained chiefly on wave-lengths of the order of 450 to 750 metres, and these in general confirm the broad conclusions drawn in Section VI of Part II of this Report from the work on longer wave-lengths.* In considering the maximum errors encountered reference may be made to p. 18, on which it was stated that while extreme variations of bearings of 125° and 100° were experienced at Orford and Slough respectively, the maximum observed error in bearing on any station was 82·7°. The statement previously made as to the extreme rarity of errors in bearing exceeding 90° is thus adequately confirmed for the whole range of wave-lengths, 450 to 9,000 metres.

One marked contrast that has been noticed between the effects on long and short waves is that whereas on the long waves the phenomenon known as " absence of signal minimum " is not very frequent at night, on the shorter waves this occurs very often and at times more than half the possible observations have been missed through failure to detect any minimum signal position for the frame coil or goniometer. This phenomenon obtained on a direction-finder with a plane vertical loop indicates definitely that the horizontal component of the magnetic field of the arriving wave can at times be of elliptical and circular rotating form in addition to its more usual linear form. Also for a range of about 100 miles it has usually been noticed on these occasions at night that the signal strength in the true minimum position is (judged aurally) at least as strong as the signal strength in the maximum position in the daytime.

Another distinction between long and short wave working that has frequently been noticed is that the rate of change of the apparent bearing at night is much greater on short than on long waves. The actual rate of change on short waves is very difficult to specify on account of the almost continuous change in character of the signal minimum which accompanies the variation.

Beyond the remarks made in the concluding section of Part II,† it has not proved possible to make any more definite statement on the times of the change from day to night conditions at various periods of the year.

The results obtained as described in this present Report confirm the previous conclusions that the extent of the night variations which are negligible for distances of less than 30 miles overland

* See Bibliography, p. 53, ref. 5, p. 103.
† *Ibid.*

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increase rapidly with distance up to a maximum for about 100 miles, beyond which no appreciable change in the nature or extent of the variations has been noticed. A fresh fact brought to light in the work on the ship transmitting stations, however, is that the minimum distance for night variations to be appreciable when the transmission is entirely oversea is about three times the above limiting distance for overland working. This is of great importance in the application of direction-finding to marine navigation and it is perhaps fortunate that the usual conditions connected therewith are accuracy in observed bearings at distances which are usually less than 50 miles and never greater than 100 miles, and which are entirely oversea. It is now known that under such conditions direction-finding is sufficiently accurate for navigational purposes. Some information is provided from these results as to the magnitude of the errors which are encountered when the direction of the transmission is within a few degrees of the tangent to the coastline. Based on the experience of the use of direction-finders on board ship, it is now becoming customary to mark out on charts the "arcs of good bearings" of various transmitting stations, which within the limits of such arcs are found to be reliable for direction-finding purposes.[12]

From various portions of the investigation in which it was possible to make a direct comparison between damped and undamped waves, it has been concluded that no effect attributable to the wave-damping has been observed. In the experiments on the wave-lengths employed for marine navigation no undamped wave transmissions could be obtained entirely oversea, but in overland working the errors and effects encountered were of the same order for damped, undamped and interrupted undamped waves. At a later date it may become possible to repeat the comparison under conditions more closely allied to those used for navigational purposes.

On the purely scientific side of the investigation and as a point of interest in connection with the theoretical explanation of the variations, it has been shown that it is not necessary for the transmitting aerial to have any unbalanced horizontal components in order to produce the usual night effects on a direction-finder. On the moderately small scale upon which these particular experiments were carried out, a vertical transmitting aerial was shown to be equally as effective as one of the inverted L type in regard to the observed errors in apparent bearing and flatness of the signal minima.

It is considered to be somewhat out of place to pursue the theoretical side of the subject any further in this Report. The aim has rather been to present, in an orderly manner, a record of the results of the investigation, with a discussion thereof, in order that they may form the basis for further study and the making of theoretical deductions in the future. Since the cessation of this investigation observations on a restricted scale have

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been continued at the Radio Research Station at Slough. These are particularly directed towards the settlement of one or two points which at present remain in a somewhat unsatisfactory state. Other experimental researches are also being pursued along lines which were directly suggested from this investigation. Two papers of interest in this connection have already been published[13], describing the beginning of a study of the propagation of wireless waves over the earth's surface by means of directional and intensity measurements of both the electric and magnetic fields of the incoming waves. One of the methods employed has enabled a direct determination of the effective conductivity of the earth to be made at wireless frequencies, this factor being of considerable importance in the general study of the propagation of waves.

The second and more recent paper referred to above describes experiments which definitely prove that some of the wireless waves received at the earth's surface from a transmitter have travelled via the upper regions of the earth's atmosphere. The angles of incidence and relative intensities of such downcoming waves have been measured; and the results show that the variations in apparent bearings on closed-loop direction-finders, which form the subject of this Report, are directly attributable to these downcoming waves when they have suitable intensity, phase, and polarisation.

(22) *Acknowledgments*

This investigation was carried out on the recommendation of the Radio Research Board, and the author is indebted to the Directional Wireless Committee of that Board for helpful advice and criticism.

The author wishes to acknowledge his indebtedness to those mentioned on p. 3 for assistance in carrying out the observations, and to Messrs. E. L. Hatcher and A. C. Haxton for assistance in connection with the special transmissions from the National Physical Laboratory, Teddington, and also in the preparation of tables and diagrams.

The author also desires to express his thanks to the Council of the Institution of Electrical Engineers for permission to base certain sections on a paper (see Bibliography, Reference [7]) by him published in Vol. 62 of the Journal of the Institution.

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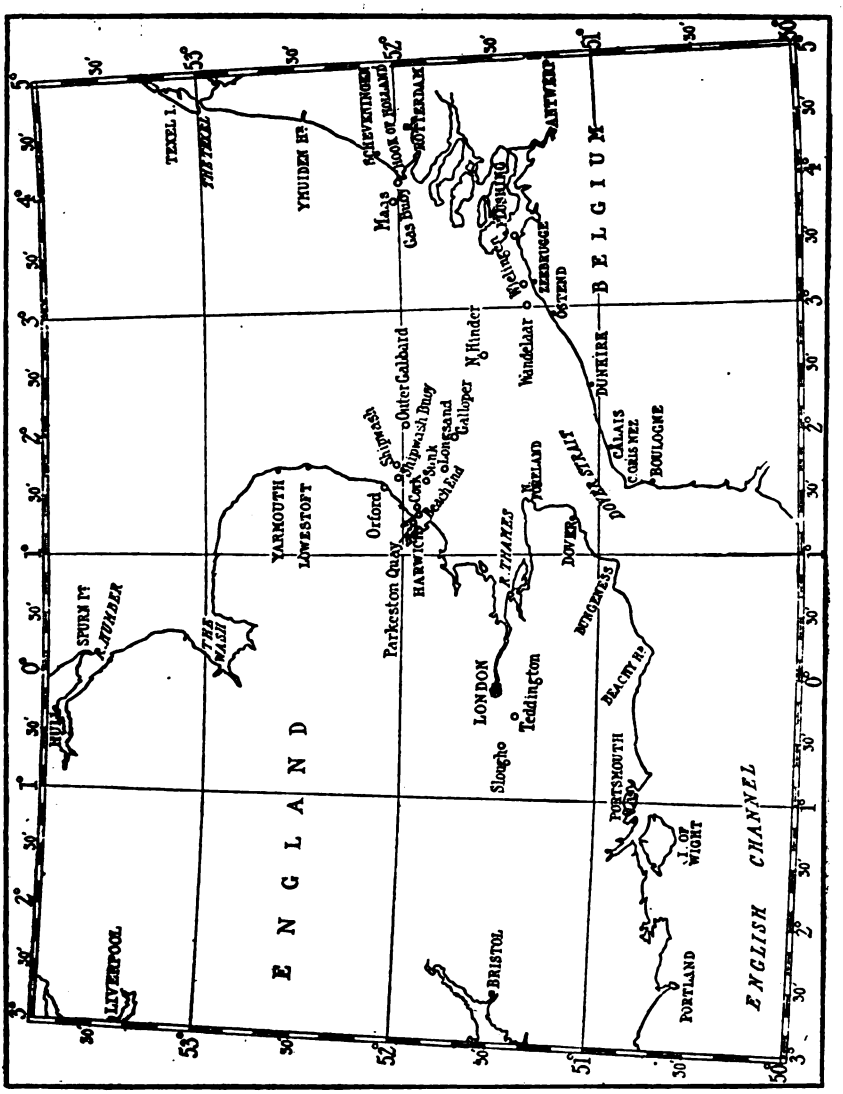

FIG. 11.—Chart showing the positions of the Stations, Light Vessels and Buoys used in the experiments carried out with the G.E.R. boats.

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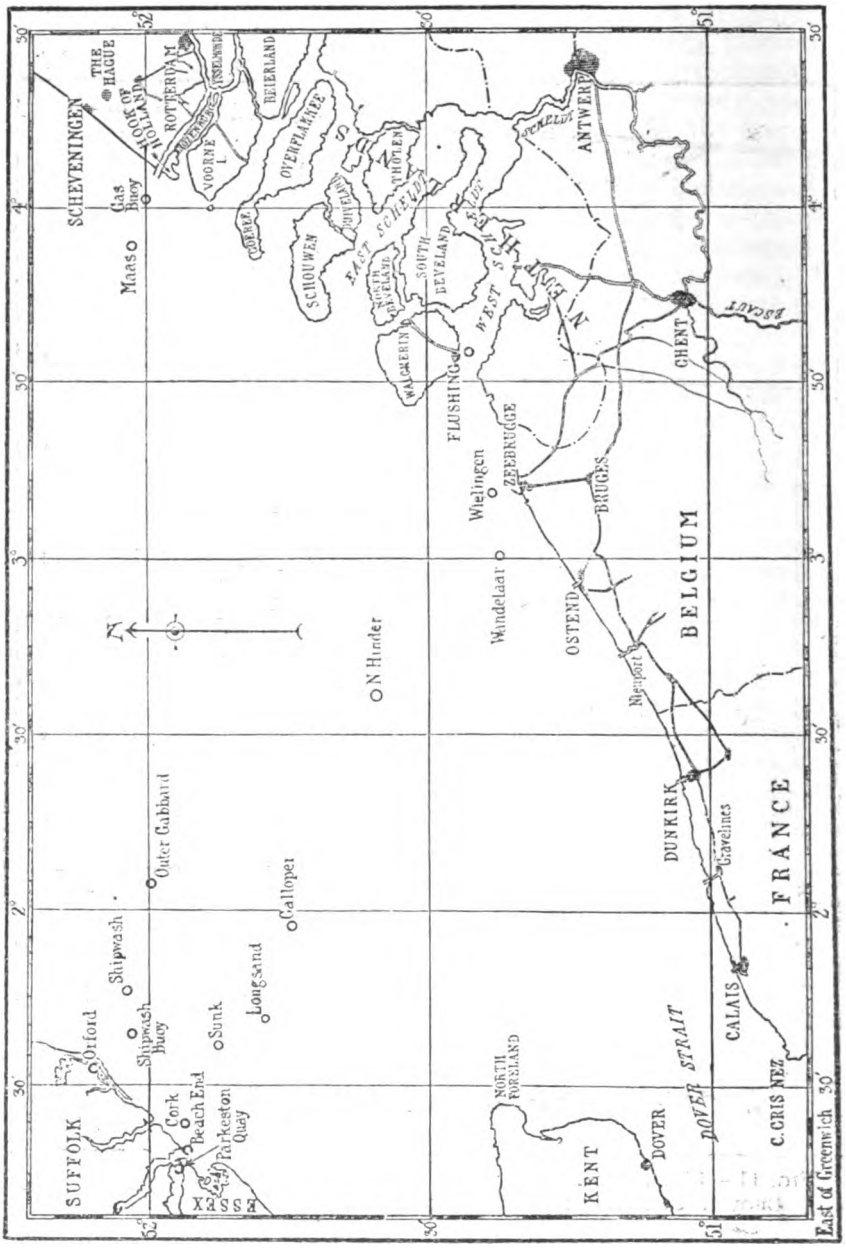

FIG 12.—Chart showing positions at which special transmissions were made by the G E R boats for bearing observations at Orford and Slough.

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SPECIAL REPORT No. 5

A STUDY OF RADIO DIRECTION-FINDING

BY

R. L. SMITH-ROSE, D.Sc., Ph.D., A.M.I.E.E.

(*National Physical Laboratory*)

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INTRODUCTORY NOTE

THE present Report summarises the progress made in the investigations on radio direction-finding, and particularly "night effect," carried out under the auspices of the Directional Wireless Committee of the Radio Research Board during the last five years. Many of the results and much of the data on which the conclusions of the Report are based have been published already, as shown in the bibliography included in the Report; the object of the Report, however, is to give a comprehensive survey of the subject, and to supplement previous records with the further information obtained during the last two years. A theoretical discussion on broad lines is also included, which indicates the contribution which the study of direction-finding has made to the solution of the problem of the propagation of wireless waves round the earth. As a direct result of the theoretical analysis arising from the investigations described, it will be seen that a system of direction-finding has been developed, in which the night errors to which all closed coil systems are apparently liable are reduced practically to a negligible extent.

F. E. SMITH,
Chairman of the Committee on Directional Wireless.

May, 1927.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH,
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A STUDY OF RADIO DIRECTION-FINDING

1. Review of the Position of Direction-Finding prior to 1921

THE subject of the present Report being the experimental investigation of the performance of the existing types of radio direction-finder, it is not intended to present here any comprehensive summary of the published literature on directive radio-telegraphy in general. An account of the fundamental principles of the subject and its historical development may be found in various published works[15, 21, 25, 56, 59]*. In order, however, to obtain a true perspective of the position of the subject at the time of the inauguration of the investigation by the Department of Scientific and Industrial Research on the advice of the Radio Research Board, it will be useful to summarise briefly the data on the performance of direction-finders published prior to 1921. The publications made during the progress of the work are referred to in their appropriate places later in the Report.

The modern radio direction-finder undoubtedly owes its success very largely to the introduction of valve amplifiers, enabling a moderately large reception range to be obtained, and its practical development therefore dates from about 1915. Previous to this, such systems of direction-finding as were in existence were confined to short-distance working, and the comparatively crude instruments then in use made accurate systematic observations difficult to obtain. As early as 1908, however, Pickard[32] observed that large errors might be obtained in the reading of coil direction-finders due to buildings, trees and other obstacles in the neighbourhood. In the diagrammatic representation of his results, these errors are shown to be approaching 90°. It was found also by Fessenden[20] in the years 1901–7, that errors in apparent direction of as much as 20° to 45° might be obtained in the indication of these instruments when receiving over a range of 100 miles. These errors were attributed to a refraction effect resulting from the difference in conductivity of land and sea-water, or even to a varying local conductivity of the ground and of vegetation. In making continuous observations day and night for a week, Fessenden was apparently the first to observe that the errors were greatest during the night, a fact which he attributed to a refraction effect of large clouds of ionised air in the path of the waves.

A method of obtaining an absolute zero of signal-strength on a small frame-coil direction-finder was described by A. H. Taylor[55] in which the " antenna effect " of the coil is compensated for by a small E.M.F. from an auxiliary frame at right angles to the

* These numbers refer to the Bibliography on page 35.

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first. Using this system at Washington, it was found that while readings taken in the daytime were fairly accurate, those taken near sunset and at night were very erratic. While it appeared that the variations observed on continuous waves of wave-length 13,600 metres were greater than on shorter waves, they were quite serious on damped waves of 1,500 metres wave-length. These variable results were briefly ascribed to reflection and refraction effects occurring during the propagation of the electromagnetic waves over the earth's surface.

The liability of the metal-work of a ship to produce a quadrantal error in the readings of a direction-finder mounted thereon was mentioned by Blondel[11] in 1919, and the corresponding effects on an aeroplane were later described by Robinson[34]. The complete theory of the effect of the metal hull of a ship on a direction-finder was first given by Mesny[29] in 1920. Calculations from this theory, confirmed by experimental results, show that the quadrantal error obtained may be as great as 12°. This error was shown to be independent of wave-length and to decrease with the height of the frame coil above the deck. Attention was also drawn in the above paper to the approximately analogous case of a direction-finder erected upon a hill or an island, and the resulting quadrantal error which may be obtained in such a case is illustrated by a curve having a maximum value of 15°.

The phenomenon of the refraction of electromagnetic waves in passing over a surface of suddenly changing conductivity was discussed by T. L. Eckersley[17] in 1920. Experimental observations made in Cyprus and Egypt on wave-lengths between 800 and 1,100 metres showed that wireless waves in crossing a coastal boundary between sea and land might suffer a deviation of as much as 4°. This deviation falls to zero for normal incidence of the waves on the coast-line, and it was also shown to be negligible for wave-lengths exceeding 2,000 metres. An interesting case is quoted in the paper of a bad day minimum being produced by the reception of two waves from a transmitter, the two waves arriving by different paths and with a phase difference which resulted in a rotating field.

Somewhat similar refraction effects on wireless waves passing from dry to wet ground and across a river were mentioned by Kiebitz[26] in connexion with experiments on a directional transmitter. The deviations of the waves amounted to 8° or 9° for a wave-length of 550 metres.

Some results showing the errors to which a radio direction-finder may be subject due to local conditions were given by Hollingworth and Hoyle[24]. Masses of metal-work, tuned circuits and overhead wires were found to produce appreciable errors in the readings.

In a most valuable paper published in 1920, Round[36] gave an account, chiefly from his personal experience, of the development and application of the direction-finder during the war. The manner in which the instrument was perfected as a useful tool

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for both military and naval purposes was described, together with the various types of errors encountered, both by day and by night. Reference was made to the work of Adcock, Eckersley and Wright in connexion with these errors, and a brief indication was given of the means by which they might be eliminated for practical direction-finding purposes.

A large amount of experimental work on the intensity and directional properties of, the electromagnetic field radiated from an aeroplane transmitter was described by Baldus, Buchwald and Hase in 1920[5, 6, 12, 13], while a mathematical treatment of this case was given by Burstyn[14]. The errors in the apparent bearings of an aeroplane at a ground direction-finding station were discussed in detail in their relation to the plane of polarisation of the emitted waves. The experiments of Baldus and Buchwald, in particular, showed that a closed-coil direction-finder on the ground could give errors of as much as 60° in the bearings of aircraft. This fact is interesting in connexion with the patent filed by Adcock[1] in 1919, in which was described a means of eliminating the error of observation of the orientation of aeroplanes.

Some further observations on the variable night errors were published in 1920 by Kinsley and Sobey[27]. Variations in the apparent bearings ranging up to 50° were recorded on wave-lengths between 960 and 17,300 metres, and for ranges of transmission from 40 up to 7,500 miles.

2. General Outline of the Present Investigation

Towards the end of 1920, the Department of Scientific and Industrial Research, on the advice of the recently established Radio Research Board, decided to erect a number of directional radio receiving sets in various parts of the British Isles, attached either to Universities or to Government experimental establishments. The object of these installations was to take regular observations of the apparent radio bearings of various transmitting stations, whose positions were accurately known, in order to obtain data on the nature, magnitude and other characteristics of the variations of bearings which were previously known to take place. While the places for observation were originally selected to obtain two or more sites on the same great circle from one land transmitting station, the final choice was made more from the point of view of availibility of both site and observer than from other considerations. Owing to the immediate availibility of suitable apparatus, the work was begun with the Robinson direction-finding system upon the European high-power " spark " transmitting stations operating on wave-lengths between 2,000 and 9,000 metres. Identical sets of apparatus were distributed among an organisation of ten observing stations which were set up in 1921, seven of these being located at British Universities. One of the direction-finding sets was erected at the National Physical Laboratory, Teddington, and was used chiefly as a

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control on the general organisation. All observers were set to work on a regular programme of observations, extending over three to four hours per day. Modifications in this programme were made from time to time to meet changed conditions, all instructions being issued from the National Physical Laboratory, where the results were sent weekly by the observers for the work of collation. Regular observations were begun at Bristol University and at the National Physical Laboratory, Teddington, on 7th February, 1921, and the remaining stations were brought into operation as soon as possible.

Early in the second year of the investigation all the direction-finders were equipped for the reception of continuous waves, and the work was consequently extended to the European C.W. transmitting stations, still, however, being confined to the comparatively long waves in the range of 2,000 to 9,000 metres.

In July, 1923, the opportunity occurred for carrying out some further observations at a station in higher latitudes than in England, viz., at Lerwick, Shetland Islands. These observations were also carried out on the comparatively long wave-lengths between 1,800 and 4,500 metres, and were continued until April, 1924.

Towards the end of 1922, the investigation was extended to much shorter wave-lengths, concentrating particularly upon 450 metres, which was the wave-length then in general use for commercial direction-finding as applied to marine navigation. Owing to the fact that only low-power transmitting stations were in operation on these shorter waves, it was found necessary to alter somewhat the location of the direction-finders for suitable observations, and the advanced stage of development of the Bellini-Tosi system made its use desirable and expedient in this particular work. In this extension of the work one of the observing stations was located on the East Coast, and a portion of the observation work was carried out with the aid of various ship-transmitting stations, whose positions were known at the time. This made it possible to compare directly the operation of the instruments in overland and oversea transmission.

The carrying out of routine observations at these various stations was discontinued in April, 1924. While the work of correlating the large number of results received was being concluded, various observations of a more specialised character were continued both at the National Physical Laboratory, Teddington, and at the Radio Research Station of the Department of Scientific and Industrial Research at Ditton Park, Slough. This latter work was undertaken simultaneously with other investigations directed towards the making of measurements on wireless waves received at the earth's surface from the upper atmosphere, and was extended to cover the range of wave-lengths between 300 and 20,000 metres. With the satisfactory demonstration, by means of several independent experiments, of the fact that the variable "night" errors encountered in radio direction-finding are due to the action of such downcoming waves, the general investigation

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on the subject was terminated in September, 1926. The object of the present Report is to give a summarised account of the whole investigation from the various aspects which have presented themselves during the past six years. The magnitude of the investigation can perhaps be judged from the fact that the total number of satisfactory readings which have been accepted for correlation is estimated to be about a quarter of a million. A simple record of the majority of these reduced to tabular form and illustrated by a large number of diagrams has formed the subject of previous reports on the investigation published by H.M. Stationery Office for the Department of Scientific and Industrial Research[38, 39, 40].

3. Experiments subsidiary to the Main Investigation

It is perhaps natural to find in the conduct of an investigation of this nature that a number of side-issues occur, each of which has to be dealt with before the general course of the main experiments can be considered satisfactory. In the present case these subsidiary experiments have been carried out simultaneously with the pursuit of the main investigation. The results of most of these experiments have already been published in various reports and papers, so that only brief mention of them will be made here in order to give a clearer idea of their relation to the main programme.

(*a*) *Instrumental Errors*

Various experiments were carried out on the Robinson direction-finders originally supplied to ascertain the limiting accuracy which could be associated with these instruments. One of the chief problems arising under this heading was that of effectively screening various parts of the apparatus. In continuous wave-working it is necessary to prevent any mutual induction between the local oscillator and the receiving frames of a Robinson direction-finder by suitably screening the local oscillator[41]. Such screened oscillators have now been in use for several years in connexion with various direction-finding work, and also with signal measuring instruments.

This work was later extended to that of screening assemblies of amplifying and receiving apparatus to prevent the undesired direct induction of signals. Data was obtained by Barfield[7] for the screening of a complete hut containing the receiving apparatus, as, for example, in the Bellini-Tosi direction-finding system. In the course of the same investigation Barfield demonstrated the properties of open wire screens, and these were later applied to the reduction of the error known as " antenna effect " in radio direction-finding.

The result of work along these lines was to show, that direction-finders could be constructed and operated on either damped or undamped waves so as to be free from any error internal to the instrument of more than 1°.

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(*b*) *Errors due to Local Conditions*

Various experiments were carried out in the early stages of the main investigation to ascertain the effect of local conditions such as metal-work, overhead wires, trees, etc., on the readings of direction-finders[46, 52]. These experiments showed that some quite large errors, ranging up to 22°, can be produced by the proximity of such obstacles, and emphasise the importance of exercising care in selecting a suitable site for a direction-finding installation. The difficulty in finding any approach to an ideal site was illustrated by the results obtained from the stations selected. In very few cases was the maximum error due to local conditions less than 2°.

It is fortunate, however, that such a type of error remains constant in value for any particular direction, so that it can be treated as of the nature of a permanent deviation, which can be ascertained periodically from a calibration of the station.

In the case of the Aberdeen station, the cause of permanent errors ranging up to 15° was traced to a long iron plate beneath the ground and supporting a sewer duct, over which the direction-finding installation was inadvertently erected[52].

(*c*) *Coastal Errors*

Another type of error, which might be classified as one due to local conditions, but which, on account of its importance in the application of direction-finding to marine navigation deserves a special section, is that due to the deviation of wireless waves in crossing a coast-line when the path of the waves lies approximately parallel to the coast. In the experimental work carried out at Orford, Suffolk, the coastal error on wave-lengths of 450 and 600 metres was found to be of the order of 3° or 4° when the direction of transmission was within 20° of the coast-line. In one instance in which the wave-length was systematically increased from 500 to 2,600 metres, the corresponding error decreased from 3·2° to 1·4°. On higher wave-lengths the observed coastal error was less than 1°. In every instance the error was such as to indicate a bending of the waves towards the normal to the coast-line in passing from the sea to the land side of the boundary. These experimental results are in complete agreement with those previously obtained by Eckersley[17] but, as already pointed out[8, 42], they are inconsistent with the explanation of the deviation as a coastal refraction effect due to the difference in the superficial velocity of wireless waves over land and sea, for the theoretical aspect of the problem would appear to indicate a deviation much smaller than that actually observed, and also in the opposite direction.

More recently some experiments on the propagation of waves across a coastal boundary have been made by Baümler and Zenneck[60]. Their results generally confirm those given above as to the magnitude and direction of the deviation of the waves

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in passing from sea to land. They further showed that the deviation at the coast is unaltered by the change in sea-level from high to low tide.

(d) Comparison of Direction-Finding Systems

As already mentioned, each of the three practical types of direction-finders, known as the Bellini-Tosi, Robinson, and Single-coil systems respectively, has been used in some portion of the investigation; and it was naturally desirable to verify whether comparable results could be obtained with any of these systems. A simple consideration of the theory shows that there is no essential difference in the basic principle of any of the systems, for in each case the reading of the direction is made as the result of some portion of the apparatus rotating about a vertical axis being set in the position in which there is a minimum, or, in the ideal case, zero E.M.F., induced by the incoming waves. This theory was discussed in a previous publication[47], which also contained a description of the results of experiments showing that each system was equally subject to variable night errors.

4. Summary of Results obtained in the Main Investigation

(a) Geographical Scope of the Observations

The location of the various observing stations equipped with direction-finding installations for the purposes of this investigation is given in Table 1, together with the period of operation and the range of wave-lengths utilised at each station. The geographical scope of the investigation is shown by the two Gnomonic charts reproduced in Figs. 1 and 2. On these charts are marked the various commercial and experimental stations upon whose transmissions regular observations were taken. Fig. 1 refers mainly to the portion of the work conducted on wave-lengths between 2,000 and 12,000 metres, while Fig. 2 shows the distribution of stations utilised for the work on the shorter wave-lengths. In addition, some more recent observations have been made at Teddington upon some of the American transmitting stations operating on wave-lengths between 10,000 and 19,000 metres, while in connexion with other investigations observations have been carried out at Slough on some of the British Broadcasting stations on wave-lengths between 300 and 500 metres.

(b) General Discussion on the Observed Variations in Apparent Bearings

The permanent errors in wireless bearings have been discussed in Section 3 above, and it was shown that these errors can be attributed to causes either local to the direction-finder or to the geographical conditions between the transmitter and receiver. While it is difficult to find an ideal site, the permanent error

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TABLE 1.—*Particulars of the Various Direction-Finding Installations employed*

No.	Situation.	Responsible Authority.	Duration of Observations.	Range of Wave-Lengths employed.
				(metres)
1	Aberdeen ..	The University ..	May, 1921, to October, 1922	2,000 to 9,000
2	Bangor ..	University College of North Wales	February, 1921, to March, 1923	do.
3	Belfast ..	Municipal College of Technology	August, 1921, to July, 1922	do.
4	Birmingham	The University ..	March, 1922, to June, 1923	do.
5	Bristol ..	The University ..	February, 1921, to June, 1923	do.
6	Cambridge ..	The University ..	April, 1921, to June, 1922	do.
7	Leeds ..	The University ..	March to July, 1921	do.
8	Lerwick ..	Air Ministry Wireless Station	July, 1923, to April, 1924	do.
9	Newcastle ..	Armstrong College	February, 1921, to June, 1923	do.
10	Orford ..	Department of Scientific and Industrial Research (Radio Research Board)	June, 1922, to March, 1924	450 to 9,000
11	Peterborough	P.O. Experimental Station	March, 1921, to December, 1922	2,000 to 9,000
12	Slough ..	Department of Scientific and Industrial Research (Radio Research Board)	January, 1922, to September, 1926	300 to 12,000
13	Teddington ..	National Physical Laboratory	February, 1921, to June, 1926	1,000 to 20,000

associated with any station does not usually exceed a few degrees, the case of Aberdeen with its error of 15° being quite abnormal[46, 52]. In addition to these permanent errors, which could be compensated for by calibration, the apparent bearings of the transmitting stations when observed under certain conditions were found to vary in a very erratic manner. The results obtained during the years 1921 to 1924 will be found tabulated in detail in previous reports [38, 39, 40]. In the work of tabulating and correlating the results it was found convenient to adopt an arbitrary division of the times of observation into day and night periods. The border lines between these periods were taken at one hour after sunrise at the westerly end of the path of transmission and one hour before sunset at the easterly end.

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With the mode of separation into day and night periods thus adopted, it was found that the extreme error experienced in the day periods was usually about 4° for any wave-length and distance of transmission, but during the winter months this limit was considerably exceeded on the higher wave-lengths, apparently because of an extension of the night conditions until three or four hours after sunrise. As an example of this phenomenon, Fig. 3 shows graphs of the daily bearings observed at Slough on the transmissions from the two stations at Leafield and Nantes, over a period of fifteen months from October, 1924, to December, 1925. The observations were made on the signals of the Union Scientifique Internationale de Radiotélégraphie sent by these stations at 1400 and 1415 G.M.T. respectively, and thus always took place in daylight. It is evident from this diagram that during the summer months the observed bearings are steady and fairly accurate, while during the winter months the daily errors assume appreciable proportions, particularly in the case of Leafield.

The general nature of the variations can be understood from the graphs in Figs. 4 to 6, which show the apparent bearings of some fixed transmitting stations as observed every few minutes over periods of 24 hours at three observing stations. It is to be noticed that the day bearings are much steadier in the summer than in the winter months, but that in either case the approach of sunset is accompanied by an increase in the magnitude and frequency of the variable errors, which continue throughout the night until sunrise. During the bulk of the investigations carried out on wave-lengths between 450 and 12,000 metres, these variable errors in bearing ranged up to, but very rarely exceeded, 90° (see references [38, 39, 40]).

In some of the more recent work the observations have been extended into the broadcasting band of wave-lengths. A summary of the results obtained is given in Table 2, and this shows that in the case of the observations at Slough taken on the transmissions from Bournemouth, the maximum error is given as ±180°. This indicates that a single minimum has been followed round the direction-finder scale through this angle, and indeed on several occasions a rotation of the apparent bearing through more than 360° has been observed. An instance of this effect is illustrated in Fig. 7. A somewhat similar phenomenon has been previously recorded by Wright and Smith [58], but on the much longer wave-length of 6,000 metres.

Another mode of illustrating the variable errors due to " night effect " is that adopted in Fig. 8. This diagram refers to records by several observers of the apparent bearings of Karlsborg during its daily transmission from 2000 to 2030 G.M.T. on a wave-length of 2,500 metres. The observations were summarised in weekly batches, and the graphs show the extreme of the bearings for individual weeks over a period of two years. It is very noticeable that the bearings show little variation so long as they are taken

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TABLE 2.—*Summary of Observations taken at Slough from 28th May to 17th December*, 1925

(The transmissions were all on telephony, of which the carrier wave was treated as C.W. for reception purposes)

(1)	(2)	(3)	(4)	(5)				(6)			
				Day Observations.				Night Observations.			
Transmitting Station.	Wave-Length.	Distance.	True Bearing.	No.	Extreme Variation.	Error of Mean.	Max. Variation from Mean.	No.	Extreme Variation.	Error of Mean.	Max. Variation from Mean.
	(metres)	(miles)	(degrees)		(degrees)	(degrees)	(degrees)		(degrees)	(degrees)	(degrees)
Birmingham ..	479	88	319·1	201	3·0	+2·0	+1·9	1378	105·0	+3·4	−67·5
Bournemouth ..	386	77	227·6	76	6·2	+0·4	+4·2	1346	> 360·0	+5·3	±180·0
London	365	18	83·5	—	—	—	—	803	7·5	+1·3	−4·8
Newcastle	404	245	350·2	—	—	—	—	537	75·0	−1·4	+51·4

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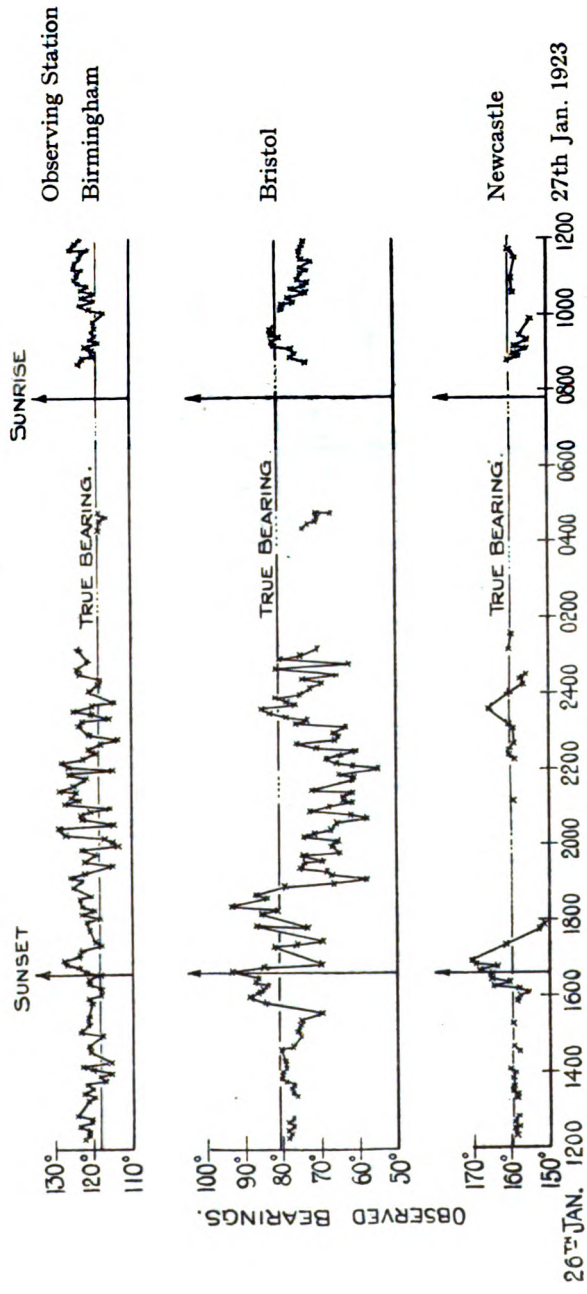

FIG. 4.—*Graphs of Observed Bearings of Ongar (Undamped Waves, $\lambda = 4{\cdot}4$ km.), taken over a 24-hour Period.*

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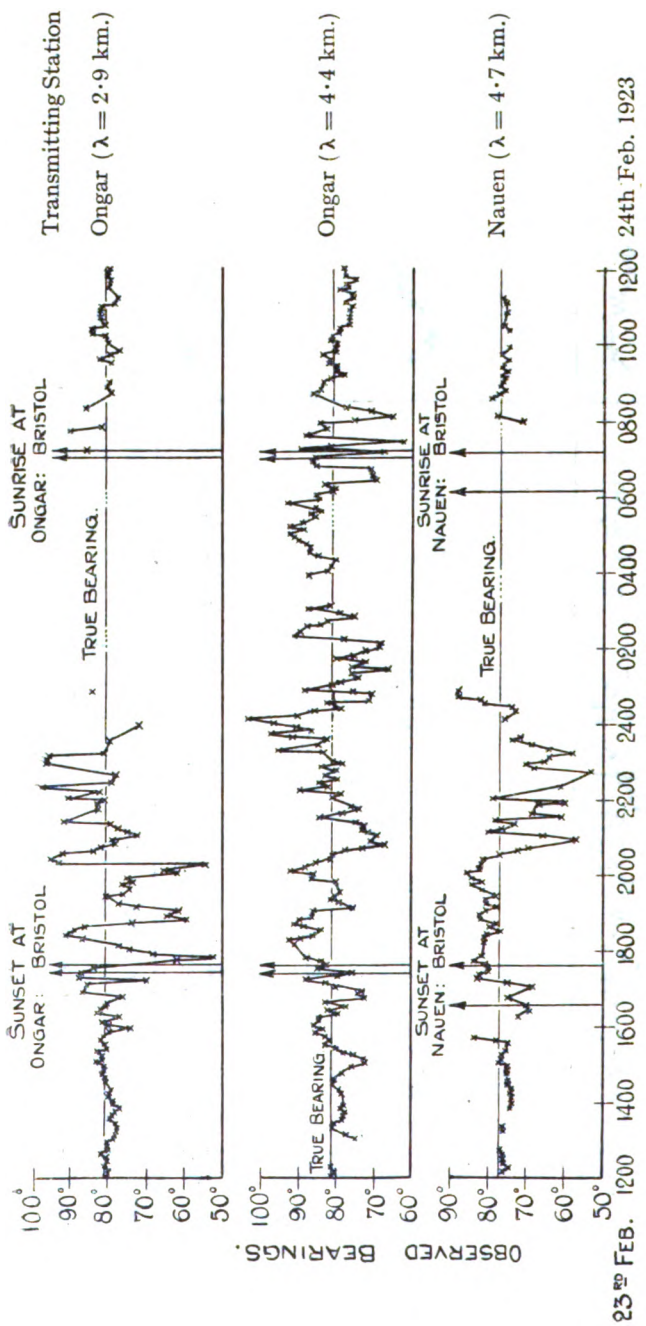
Transmitting Station
Ongar (λ = 2·9 km.)
Ongar (λ = 4·4 km.)
Nauen (λ = 4·7 km.)
SUNRISE AT ONGAR: BRISTOL
SUNSET AT ONGAR: BRISTOL
SUNRISE AT NAUEN: BRISTOL
SUNSET AT NAUEN: BRISTOL
TRUE BEARING.
OBSERVED BEARINGS.
HOURS G.M.T.
23rd FEB. 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 24th Feb. 1923

FIG. 5.—*Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 km.) and Nauen (Undamped Waves, λ = 4·7 km.) taken at Bristol over a 24-hour Period.*)

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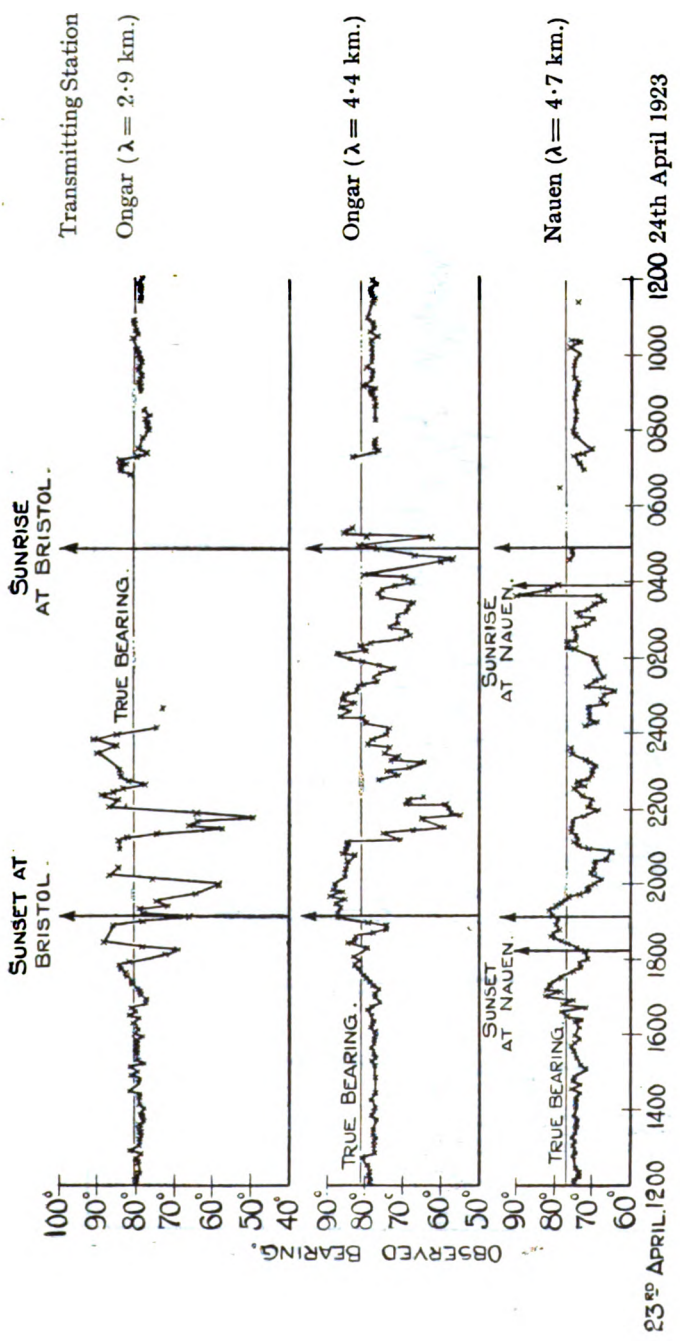
Transmitting Station
Ongar (λ = 2·9 km.)
Ongar (λ = 4·4 km.)
Nauen (λ = 4·7 km.)
SUNSET AT BRISTOL.
SUNRISE AT BRISTOL.
TRUE BEARING.
SUNSET AT NAUEN.
SUNRISE AT NAUEN.
OBSERVED BEARING.
100° 90° 80° 70° 60° 50° 40°
90° 80° 70° 60° 50°
90° 80° 70° 60°
23RD APRIL 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 24th April 1923
HOURS G.M.T.

FIG. 6.—*Graphs of Observed Bearings of Ongar (Undamped Waves, λ = 2·9 and 4·4 km.) and Nauen (Undamped Waves, λ = 4·7 km.) taken at Bristol over a 24-hour Period.*

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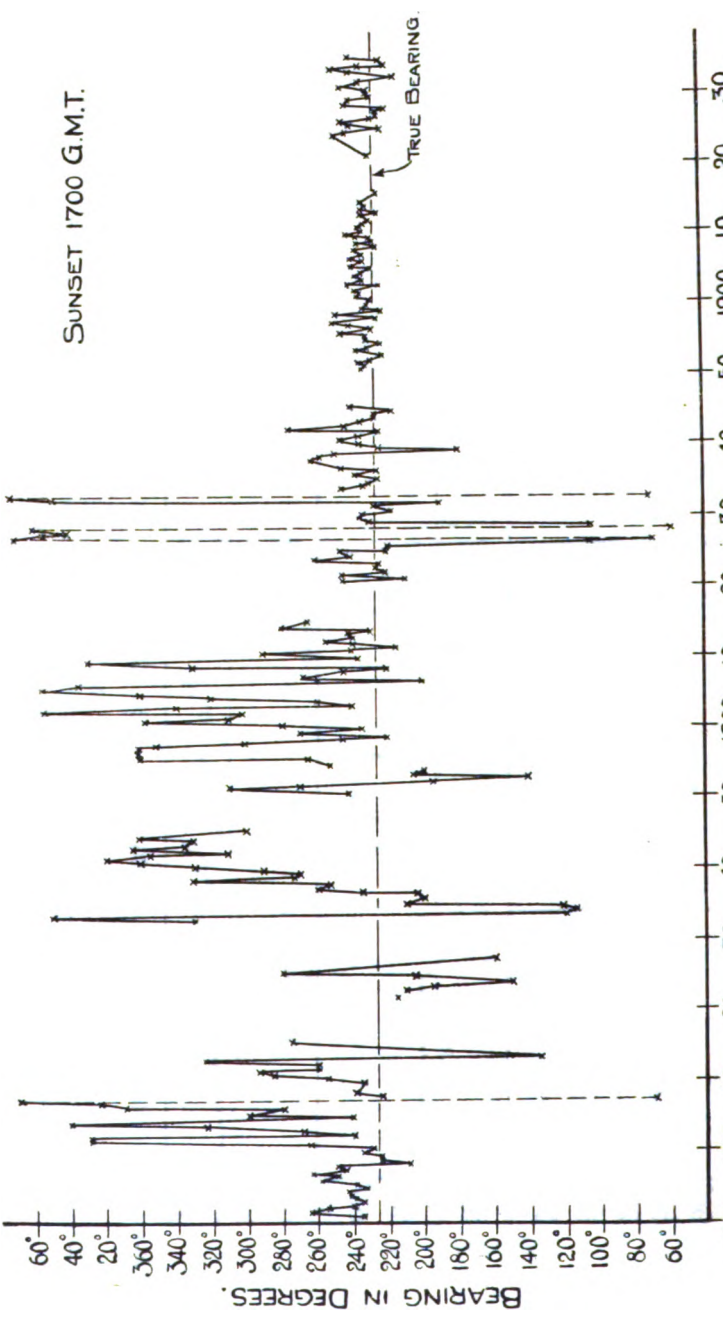

FIG. 7.—*Graphs of Observed Bearings of Bournemouth (Undamped Waves, λ = 386 m.) taken at Ditton Park, Slough, 20th October, 1926.*

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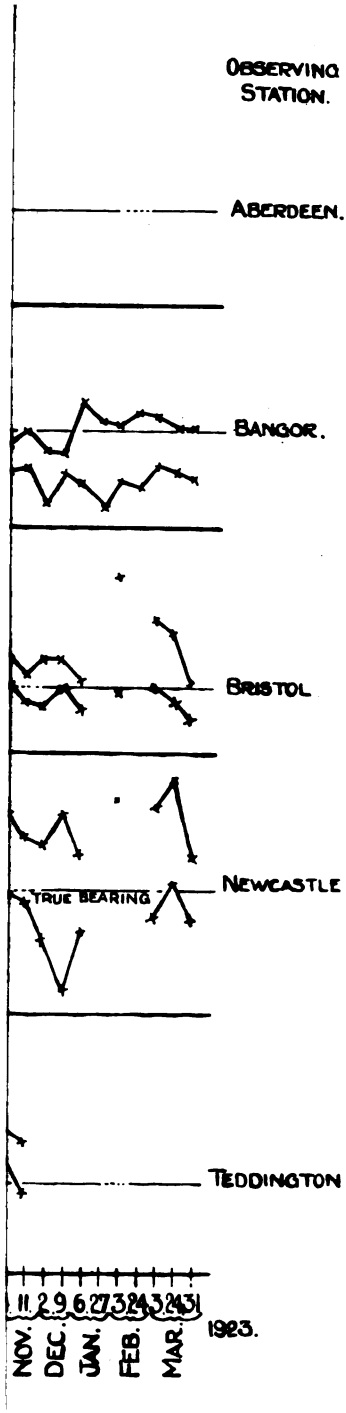

KARLSBORG

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MARCH 1923.

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before sunset at the receivers, even though darkness has prevailed over a portion of the path of transmission for some time. On the other hand, similar observations during the same periods taken on Leafield and illustrated in Fig. 9 show that the variable night errors begin before sunset occurs over the path of transmission.

In spite of the large variations in apparent bearings described and illustrated above, it is noteworthy that during the night periods the observed bearings show no signs of a definite systematic error, and so the variations are, on the whole, equally distributed about the mean value. Another feature to be observed in connexion with the magnitude of the night variations is the comparative rarity of the larger errors. The results given in previous reports [38. 39. 40] show that it is not often that more than 15 per cent. of the night results give an error exceeding 10°. This fact, combined with the absence of a systematic error at night, is of great importance in the practical application of wireless direction-finding. The period over which it is necessary to take a series of observations, in order to secure that the mean bearing is approximately the same as the true bearing, depends upon the wave-length employed. On wave-lengths of the order of 5,000 to 20,000 metres, the error in bearing at night varies comparatively slowly, and observation may have to be taken for a period of an hour or more; but on the shorter wave-lengths of 300 to 1,000 metres, the variations are much more rapid, and the mean of a series of readings at half-minute intervals, taken over a period of 10 to 15 minutes, usually approximates very closely to the true bearing.

It thus appears that the chief effects to be observed in radio direction-finding are generally as follows:—In the summer time, in those latitudes in which the United Kingdom is situated, the observed bearings in daylight are fairly constant, and, with the exception of the permanent errors already mentioned, they approximate quite accurately to the true geographical bearing of the transmitting station. Under certain conditions of transmission to be referred to below, this accuracy is maintained at all times and seasons. When these conditions do not prevail, however, the observed bearings show signs of variable errors as the setting of the sun approaches the path of transmission. These variations then prevail throughout the night, but decrease to a negligible extent soon after sunrise. As the seasonal conditions are changed gradually from summer to winter, the variations in the daytime increase somewhat; and the night conditions begin an appreciable time before sunset and continue until some time after sunrise. In the midwinter conditions represented by January, the change from day to night effects is very much more gradual, and the difference is only distinguishable by the difference in magnitudes of the variations. At this time of year it appears that the variations on the longer wave-lengths above 2,000 metres may have an amplitude of the order of 10° or more during

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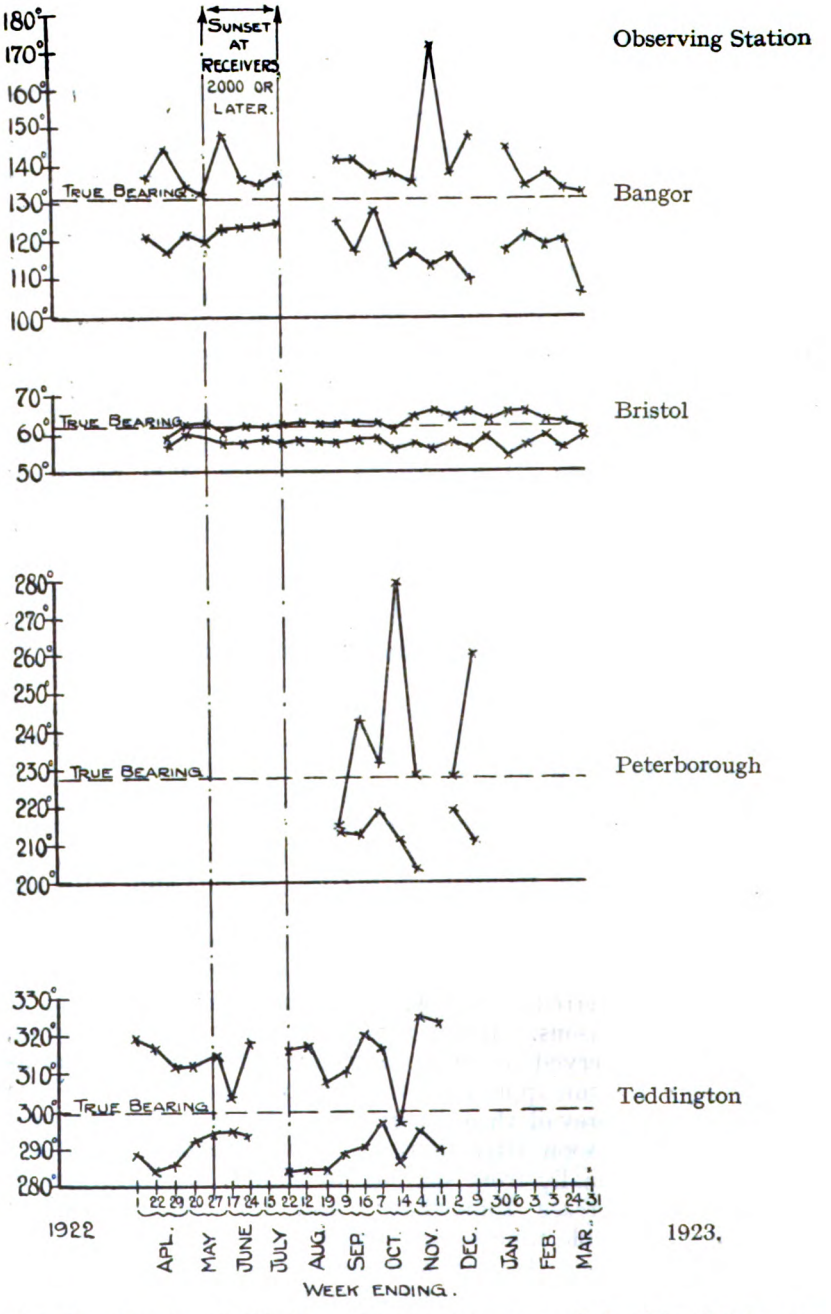

FIG. 9.—*Graphs of Weekly Extreme Bearings of Leafield (Undamped Waves, $\lambda = 8{\cdot}7$ km.) observed on the Transmissions at 2000 G.M.T.*

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the daylight hours, and this increases rapidly at about one hour before sunset to the night value of 50° or 70°, and so continuing in the most erratic manner until one hour or so after sunrise.

This aspect of the results would appear to indicate, *per se*, that the effects cannot be subjected to a definite division between daylight and darkness, but rather that the variations are dependent upon the altitude of the sun and the intensity of its radiation in some portion of the earth's atmosphere. For example, in Great Britain, the maximum altitude of the sun at 21st March and 21st September is about 38°, increasing to 61° on 21st June and decreasing to 15° on 21st December. Since no effect of rain, cloud or fog has ever been noticed in the apparent bearings, it may be concluded that it is not the intensity of the solar radiation at the earth's surface which is important. Indeed, as will be explained below, it is now known that the variations of bearings under discussion are due to the deflection of waves by the upper ionised portions of the earth's atmosphere and their return to earth at various angles of incidence. Pursuing the discussion of the present results, it appears that during the summer half-year between March and September, the intensity of the solar radiation is sufficient almost immediately after sunrise to produce the necessary ionisation in the lower atmosphere to cause a cessation of the variations. As the season progresses, a longer time after sunrise must elapse before the radiation is sufficiently intense to stop the variations, until in the midwinter conditions with the corresponding very low altitude of the sun, the radiation is not sufficiently intense at any time of the day to stop altogether the variations, but only to cause a decrease in their magnitude. This explanation would account for the comparatively large variations experienced even near midday in the winter months of November to February, and would also account for the very large day variations obtained in some cases at Lerwick in the extreme north of the British Isles, where, of course, the sun's altitude will be about 8° less than in the south of England.

(c) *Conditions Affecting Direction-Finding as an Aid to Navigation*

The minimum distance at which night variations have been consistently experienced is about 30 miles for overland working, observations taken at closer ranges than this showing a maximum error of only 2° or 3°. Mesny[30] has stated that night variations may occur for ranges of transmission as small as 15 miles, but according to the author's experience, night errors are small, although definite at such distances. For example, observations of the bearings of the London Broadcasting station taken at Slough, 18 miles away, have shown a maximum error of less than 5° during many months (see Table 2). Similarly, the bearings of the Air Ministry station at Kidbrook, near London, observed at Teddington, distance 17 miles, have shown a maximum error

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of 4·5°, while 99 per cent. of the readings were within 2° of the mean bearing. On the other hand, Ongar, which is 30 miles away, gave an error up to 8° at the same observing station, and only 14 per cent. of the readings differed from the mean by less than 2°. When, however, the path of transmission is entirely oversea, as was the case in the observations carried out at Orford on the transmissions from various ships, the above minimum distance is increased to about 80 or 90 miles[43]. This fact is of great importance in the application of direction-finding to marine navigation, and it is perhaps fortunate that the usual conditions connected therewith are that the path of transmission is entirely oversea and that the observed bearings should be accurate at distances which are usually less than 50 miles and never greater than 100 miles.

It is now known that under such conditions direction-finding is sufficiently accurate for navigational purposes. Even in the presence of night errors their effect can be largely mitigated by taking a series of observations in succession over a period of a few minutes, when the mean bearing so obtained will be much more accurate than a single reading. In connexion with the application of direction-finding to marine navigation, it is evident that a knowledge of the coastal errors experienced when the direction of transmission is within a few degrees of the coast-line is very important. This type of error has already been dealt with in Section 3 (*c*) above, but it is worthy of note that, with the accumulation of experience of the use of direction-finders on board ship, it is now becoming customary to mark out on charts the " arcs of good bearings " of various transmitting stations, within which the results of observations are found to be reliable[37]. Similar arcs can, of course, be provided for shore direction-finding stations, and their boundaries would be found in the initial calibration of the station for the permanent local errors.

From various portions of the investigation in which it was possible to make a direct comparison between damped and undamped waves, it has been concluded that no effect attributable to the wave-damping has been observed[44]. In the experiments on the wave-lengths employed for marine navigation, no undamped wave transmissions could be obtained entirely oversea, but in overland working the errors and effects encountered were of the same order for damped, undamped, and interrupted undamped waves. At a later date it may become possible to repeat the comparison under conditions more closely allied to those used for navigational purposes.

An important factor to be noted from a navigational point of view is that of any effect of fog on direction-finding, since it is chiefly during foggy weather that the majority of direction-finding stations are called into action. On several occasions the author has taken particular notice of the existence of fog at times when observations were in progress, with a negative result. On one occasion in particular the fog was spread over the British

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Isles and a large portion of Western Europe, but the directional variations showed nothing beyond the usual day and night effects. These results form a confirmation to the observations of Rothé[35], who concluded that no variations in ordinary atmospheric conditions would account for the small variations in bearings observed in the daytime.

(d) Effect of Wave-Length, Distance and other Conditions

From time to time throughout the investigation the results have been carefully considered to ascertain if there is any definite relation between the wave-length of transmission and the nature, frequency and magnitude of the variations in apparent bearings experienced. Over the band of wave-lengths from 350 to 19,000 metres, no marked difference has been observed in the extreme variations recorded, after due allowance has been made for the distance and the geographical conditions over the path of transmission. The outstanding exception to this statement is the case of the observations of Bournemouth taken at Slough, as mentioned above, in which exceedingly violent variations have been recorded. Apart from this, however, there are two very noticeable features in the results obtained on the above range of wave-lengths. The first of these concerns the quality of the signal mimimum observed at night as compared with the well-defined arc of silence experienced in the daytime. On the longer wave-lengths, *i.e.*, above 2,000 metres, it was only on very rare occasions that the minimum became so ill-defined that a bearing observation was impossible. On wave-lengths under 2,000 metres, and particularly those from 350 to 500 metres, the occurrence of this very broad minimum was comparatively frequent, and in some cases about half the observations resulted in no bearing being observed on account of the absence of any detectable minimum for different settings of the direction-finding coil. The second feature of the records is that the maximum rate at which the apparent bearings vary at night is very much greater on the short than on the long waves. For example, in the observations recorded over the wave-lengths range of 2,000 to 9,000 metres, the maximum rate of variation of bearings was about 37° in ten minutes, whereas on the wave-length of 450 metres, variations of about 40° per minute were of frequent occurrence. The comparatively slow drift of the apparent bearings on long waves is illustrated by the graph in Fig. 11, which shows the results of observations taken at Teddington over a 24-hour period on transmissions from Ste. Assise, on a wave-length of 14,300 metres. Such slow variations have been remarked upon by Pickard [33], and those illustrated in Fig. 11 are to be contrasted with those found in the observations on the transmissions from Bournemouth, when, as illustrated in Fig. 7, the apparent bearing was rotated through more than 360° at a rate of about 180° per minute. The conclusion that, within wide limits, the wave-length has

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no effect upon the amplitude of the variations observed over a period is to be distinguished from the fact that when the wave-length of transmission is changed instantaneously, the error in bearing due to night effect also changes appreciably. Excellent examples of this occurrence have been obtained in observing on the transmissions from arc stations, such as Leafield, which employ for signalling purposes a marking and spacing wave differing in length by about 1 per cent. The errors in bearing taken in rapid succession on the marking and spacing waves differed at times by 20° to 30°.

In the previously published official reports[38, 39, 40] it was concluded that the effect of distance on the variations of bearings was briefly as follows:—For distances up to 17 miles the extreme variations at night are of the same order as in the daytime. When the transmission is entirely over land and exceeds 30 miles, the night variations become appreciably greater. From this point the extent of the variations increases with the distance of transmission up to about 150 miles, beyond which the variations appear to remain of the same order for greater distances up to 1500 miles, which was the limiting distance employed in this portion of the investigation.

Since the above results were published, an attempt has been made to extend the scope of the investigation to greater distances, and by utilising the transmissions from the American station a comparison of the variations has been made over various distances on wave-lengths between 14,000 and 19,000 metres. A summary of the results obtained in this work during a series of continuous tests made over 24-hour periods is given in Table 3. These later experiments have shown that over similar distances the variations experienced on the wave-lengths 2,000 to 9,000 metres are of the same order as those on the higher wave-lengths, and also that the actual amplitudes of the variations decrease considerably for a range of transmission of 3,000 miles. In fact, on the American transmitting stations the variations in bearings show no marked distinction between day and night periods. As illustrated in Table 3, observations taken over several 24-hour periods show a maximum error in bearing of about 3° for the American stations, while on nearer European stations the night error may range up to nearly 30°. From Table 3 it is seen that of the two American stations observed, one gave 94 per cent. and the other 100 per cent. of bearings correct within 2° during the whole series of tests; whereas of the European stations, the best example, Carnarvon, gave only 63 per cent. of bearings correct to within this limit. The contrast of the observations on the stations at different distances is illustrated by Figs. 10 and 11, which are typical of the results obtained on transmissions from the American and European stations. The mean error of the daylight readings is in each case to be regarded as a permanent error attributable to local conditions at the direction-finder.

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TABLE 3.—*Summary of Observations taken at Teddington during 24-hour Tests from January to June,* 1926

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)			
Transmitting Station.	Wave-length.	Distance.	True Bearing.	No. of Obser-vations.	Extreme Varia-tion.	Error of Mean Bearing.	Max. Varia-tion from Mean.	Percentage of Bearings differing from Mean by more than :—			
								2°	5°	10°	20°
	(metres)	(miles)	(degrees)		(degrees)	(degrees)	(degrees)				
Bordeaux .. LY	18,940	452	181·8	316	33·0	−0·2	−19·1	63·3	32·6	5·4	0·0
Carnarvon .. MUU	14,200	200	307·3	139	7·7	+1·3	−4·6	36·9	0·0	0·0	0·0
Karlsborg .. SAQ	18,050	760	44·4	219	19·8	+2·9	−11·6	55·7	11·9	0·9	0·0
Long Island .. WQK	16,460	3,403	287·9	547	7·4	+2·3	+3·4	6·4	0·0	0·0	0·0
Rugby .. .. GBR	18,900	75	330·4	147	34·5	−1·3	+27·9	85·8	47·7	11·6	4·8
St. Assise .. UFT	14,290	237	146·3	416	34·0	−3·9	−22·4	83·7	35·4	9·4	0·3
Tuckerton .. WCI	16,800	3,521	287·3	192	3·7	+2·4	+2·0	0·0	0·0	0·0	0·0

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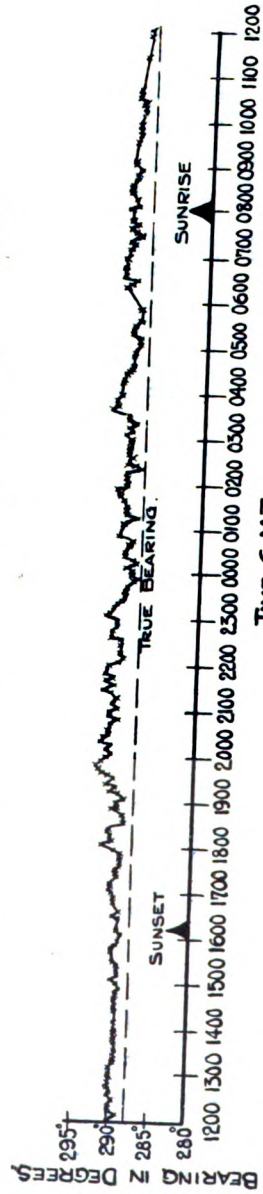

FIG. 10.—*Graph of Observed Bearings of Long Island (WQK, λ = 16·5 km.) taken at Teddington during a 24-hour Period, 13th to 14th January*, 1926.

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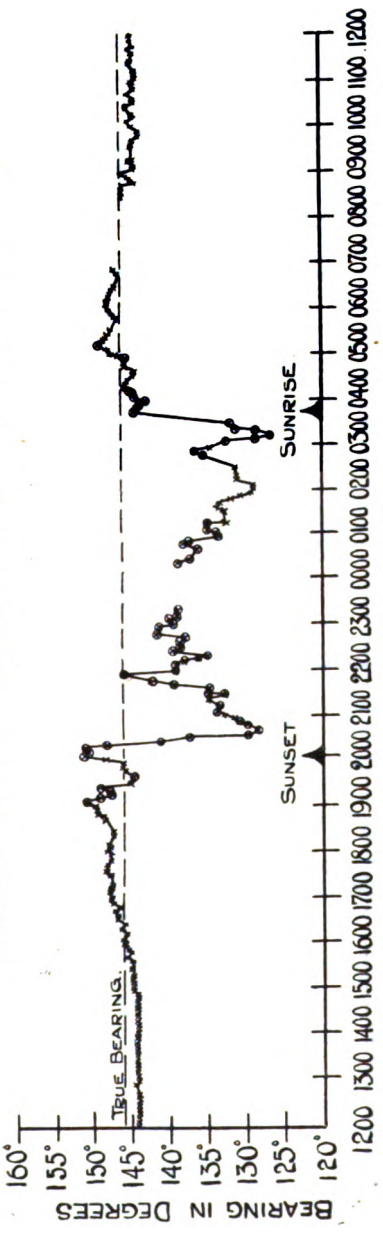

FIG. 11.—*Graphs of Observed Bearings of Ste. Assise* (*UFT*, $\lambda = 14{\cdot}3$ *km.*) *taken at Teddington during a 24-hour Period, 2nd to 3rd June*, 1926.

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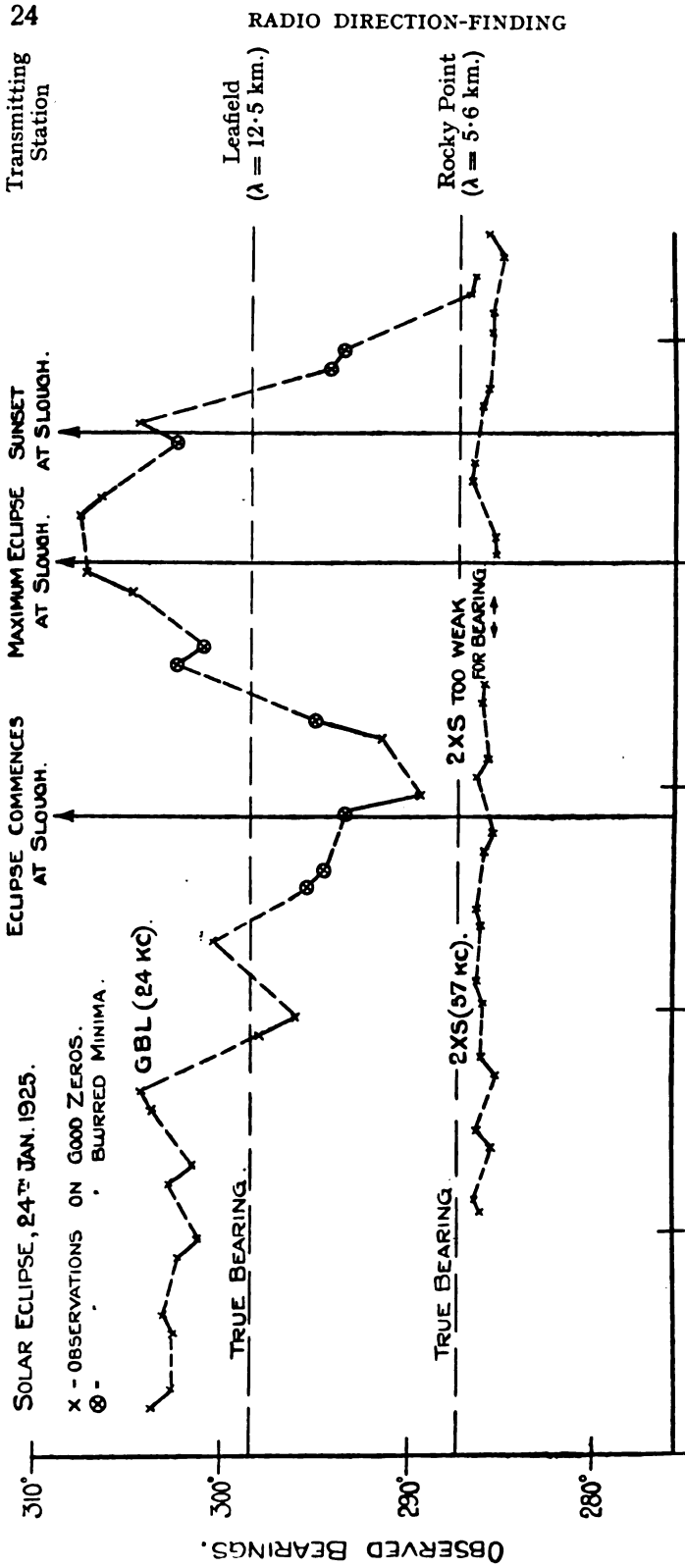

FIG. 12.—*Graphs of Observed Bearings of Leafield, England* ($\lambda = 12{\cdot}5$ *km.*), *and Rocky Point, U.S.A.* ($\lambda = 5{\cdot}6$ *km.*), *taken at Ditton Park, Slough, during the Solar Eclipse of 24th January*, 1925.

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Fig. 12 shows the results of observations made during the same period on Rocky Point (2XS), Long Island, and Leafield (GBL) during the solar eclipse of January, 1925. In this case, the American station was transmitting on a wave-length of 5,000 metres, and the observed bearings are seen to be as free from error as with the long wave transmissions.

While discussing the effect of distance on the errors in observed bearings, it may be mentioned that Pickard[33] published in 1922 some results, of which a very noticeable feature was that the apparent bearings of European stations observed at Maine, U.S.A., showed much smaller variations than the bearings of some American stations. This difference was attributed to the fact that the transmission from the former was mostly over sea, whereas in the latter case it was entirely over land. It will be seen in the theoretical discussion below, however, that this is probably not the correct explanation. Mesny[30] has also found that the bearings on some American stations observed in France show only a very small variation as compared with bearings taken on the nearer European stations. Experiments carried out in Shanghai by Gherzi[22] during 1923–24 have also shown that while large night errors are observed for distances of transmission of less than 5,000 km. (3,000 miles), these errors have an extreme value of about 6° when the range of transmission is from 5,000 to 12,000 km. (3,000 to 7,500 miles).

In concluding this Section, it may be repeated that it is only intended to be a general summary of the results obtained from the co-ordination of a large quantity of data. The reader who is interested in obtaining more exact information on any portion of the work may be referred to the previous reports containing the tabulated results in detail.

As far as the actual nature and magnitude of the effects observed are concerned, the author believes he is correct in stating that his results obtained in the British Isles are in complete agreement with the observations made in other countries, such as by Mesny and others in France[19, 30, 31], by Stoye in Germany[53], Austin[3], Bidwell[10, 28], and Pickard[33] in America, and by Gherzi[22] in China.

5. The Theory of Night Errors and its Experimental Verification

The theoretical explanation of the cause of the variable night errors in radio direction-finding was first described in some detail by T. L. Eckersley[18] in 1921. About nine years previously Eccles[16] had put forward the now well-known Heaviside layer theory of wireless wave propagation.

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In order to overcome the difficulty of explaining the propagation of wireless waves around considerable portions of the earth's circumference by the aid of pure diffraction, Eccles suggested that those waves from the transmitting station which had travelled into the upper regions of the earth's atmosphere were deflected at an ionised layer and returned to the earth's surface at a distant receiving station. At short distances from the transmitter the magnitude of such a deflected wave would be small, and only the wave transmitted directly along the earth's surface would be of importance in producing the received signal. At medium distances, both the direct wave along the earth's surface and the indirect wave deflected from the upper atmosphere would be received; while at great distances the major part or the whole of the received signal would be due to the indirect wave. The angle of incidence of this downcoming wave on the earth's surface will obviously depend principally upon the height of the deflecting layer and the range of transmission. In Eckersley's extension of this theory, it was shown that while the transmission of vertically polarised* waves via the Heaviside layer was sufficient to explain the measured values of wireless signal strength, it was necessary to assume that the downcoming waves at the receiving end contained an horizontally polarised component in order to explain the variations in apparent bearings observed on direction finders. In the same paper Eckersley described experiments which supported the theory, and of recent years considerable confirmation has been provided by the work of other experimenters[2, 23, 48].

It has been suggested by Bellini[9] and others that the horizontally polarised component of the electric force in the waves originates in the horizontal components of the transmitting aerial; but the present author[45] has demonstrated experimentally that directional errors are still experienced when a simple vertical aerial is employed at the transmitting end, and that the addition of horizontal portions to the aerial had, in the case of his experiments, no detectable influence on the errors observed.

The manner in which the theory is applied in the case of direction-finding may be understood with the aid of Fig. 13, which represents the manner of arrival of the direct and indirect waves between the transmitter and receiver. We suppose that our direction-finder is located at the receiver R. The direct wave proceeding along the earth's surface is assumed to have an electric force E_0 in the vertical plane of propagation, and a horizontal magnetic force H_0 perpendicular to E_0 and to the direction of the wave. It is known from previous experiments that on all but short waves E_0 is sensibly vertical under all conditions[50]. The indirect wave arrives at the earth's surface at an angle of incidence θ as shown, and as it may be of complex polarisation let it be resolved into two components polarised in

* An electromagnetic wave is here assumed to be polarised in the plane containing its electric force and direction of propagation.

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and perpendicular to the plane of incidence. The forces in these two components may then be represented by the vectors E_1H_1 and E_2H_2 respectively. On meeting the surface of the earth, these incident waves will give rise to two reflected waves with component forces $E^1_1H^1_1$ and $E^1_2H^1_2$, as shown.

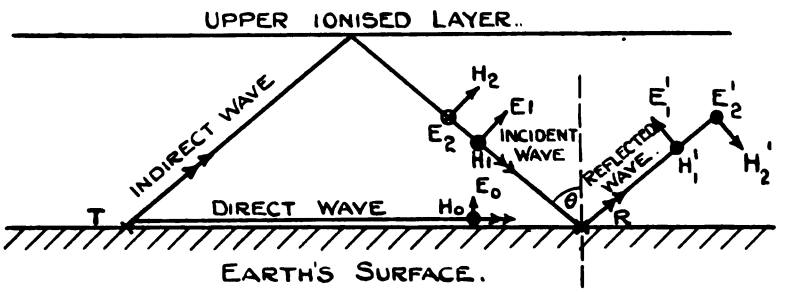

FIG. 13.—*Diagrammatic representation of the forces in the direct and indirect waves arriving at a receiver situated on the earth's surface.*

At the receiving point R we may take co-ordinate axes as shown in Fig. 14, Ox being the horizontal direction of propagation of the wave. The resultant magnetic force at O, due to all the waves received may then be designated by the components α, β, γ along the axes Ox, Oy, Oz respectively.

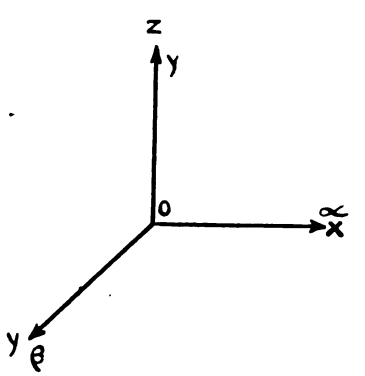

FIG. 14.—*Co-ordinate axes used for discussion in Section* 5.

A simple consideration of the case outlined will then show that

$$\left.\begin{aligned} \alpha &= H_2 (1 + \rho_h) \cos \theta \\ \beta &= H_0 + H_1 (1 + \rho_v) \\ \gamma &= H_2 (1 - \rho_h) \sin \theta \end{aligned}\right\}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where ρ_h, ρ_v are the reflection coefficients of the ground for waves horizontally and vertically polarised.

The values of ρ_h and ρ_v can be obtained from Fresnel's equations, taking a value for the refractive index of the ground based on its known constants and the frequency of the waves.

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If the transmitted waves have a frequency $\frac{\omega}{2\pi}$, equation (1) can be put in the form

$$\left.\begin{aligned} \alpha &= h_2 (1 + \rho_h) \cos \theta \sin (\omega t + \chi_2) \\ \beta &= h_0 \sin \omega t + h_1 (1 + \rho_v) \sin (\omega t + \chi_1) \\ \gamma &= h_2 (1 - \rho_h) \sin \theta \sin (\omega t + \chi_2) \end{aligned}\right\} \ldots\ldots\ldots (2),$$

where χ_1 and χ_2 indicate the phases of the incident wave components with respect to that of the direct wave.

It is evident from these equations that if all the received waves are travelling along the ground, then $\theta = 90°$ and $\gamma = 0$. The existence of a magnetic field γ perpendicular to the earth at a time when night errors were experienced on a direction-finder was demonstrated experimentally by Eckersley, and formed a proof of the arrival of downcoming waves with a horizontally polarised component.

Operating on the same principle Barfield and Smith-Rose[48] have employed a coil receiver rotating about a horizontal axis to measure the angle of incidence of waves deflected from the upper atmosphere. In this country, the conductivity of the ground is so high that on the longer waves the value of γ is too small to detect by such means, but some experiments carried out by Austin[4] in America on a wave-length of 13,600 metres showed that appreciable tilts of the magnetic field to the horizontal accompanied the inception of directional errors in the neighbourhood of sunset. In the usual manner of operating a direction-finder with the plane of the receiving coil vertical, it is evident that γ will be ineffective in producing an E.M.F. therein. Now in the absence of an indirect wave, the only magnetic field acting on the direction-finding coil will be β, and the minimum signal position will be found when the plane of the coil is parallel to β, *i.e.*, perpendicular to the direction of transmission. When, however, α has a finite value due to the arrival of horizontally polarised downcoming waves, a signal will be received on the coil previously set in this minimum position, and the coil will have to be rotated to some extent to find a fresh minimum position making an angle C with the true position.

In general it may be assumed that α and β will be out of phase and the resultant magnetic field at the receiver will thus be elliptically polarised, and C will be the angle between the major axis of this ellipse and the direction of β. The relative magnitudes of the major and minor axes of the ellipse will represent the quality of the signal minimum upon which the bearing is observed. All the conditions met with in practical direction-finding can thus be explained if appropriate values of the various quantities involved in equation (2) are inserted. If α and β are in phase, they will produce a linear resultant field displaced by an angle C from the direction of β, where

$$\tan C = \frac{\alpha}{\beta} = \frac{h_2 (1 + \rho_h) \cos \theta \sin (\omega t + \chi_2)}{h_0 \sin \omega t + h_1 (1 + \rho_v) \sin (\omega t + \chi_1)} \ldots\ldots (3).$$

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The bearing observed will therefore be sharply defined, and will be in error by the angle C.

It now remains to be shown whether in practice the incident waves can have values of amplitude, phase and angle of incidence, which together will account for the errors in bearing experienced. This matter is best studied by considering a number of special cases in which the dimensions of α and β can be estimated from other measurements made on the received signals independently of, and approximately simultaneously with, the directional observations.

Case I. Correct Bearing Observed in the Presence of Downcoming Waves

This case evidently requires that $\alpha = 0$, a result which may be brought about by reducing to zero either h_2 or $\cos \theta$. This means that either the whole of the downcoming waves are vertically polarised or that the angle of incidence is 90°.

Now in the case of the simultaneous observations of bearings and signal intensity carried out at Slough, there have been long periods during the summer months when the day variations in apparent bearing were of a very small order. Hollingworth has demonstrated that even in this and similar cases[23] there is still a portion of the received wave energy which has arrived from the upper atmosphere. During the summer months the intensities of both the direct and the downcoming waves are reasonably constant in daylight on successive days, and the two waves may assist or oppose each other according to their relative phases at different distances. Since no variations of bearings are experienced at these times, it is evident that the downcoming waves are practically entirely vertically polarised. As sunset is approached or as the day observations are continued into the winter months, errors in apparent bearing are experienced indicating a rotation of the plane of polarisation. Since the change in conditions giving rise to this effect is now understood to be an increase in height of the deflecting layer, it would appear that there is a minimum height at which the deflection of waves by the ionised air can be accompanied by a rotation of the plane of polarisation of the waves.

Returning to the other condition in the present case, it would appear that the absence of any variations in direction of the American transmitting stations observed in Europe is due to the fact that the waves arrive at tangential incidence. Assuming that the height of the deflecting ionised layer is at 70 km. for wave-lengths of the order 5,000 to 20,000 metres, then a wave leaving the earth in a horizontal direction will return to the earth at tangential incidence at a distance of about 1,790 km. (1,120 miles) Hence it is necessary for the waves to have suffered three such deflections from the ionised layer in order to traverse the distance of more than 3,400 miles between New York and Teddington. Since night direction variations are experienced

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at distances of and in excess of 1,120 miles (*e.g.* Moscow to Newcastle —1,520 miles), it is evident that the waves arriving at tangential incidence are accompanied by other waves which have suffered more reflections and consequently arrive at an appreciably smaller angle of incidence. It is these latter waves which give rise to the directional variations, but in the case of greater distances their intensity is evidently too small for them to play an appreciable part in the field at the receiver. Owing to its lower conductivity, the reflecting power of land is less than that of sea-water. The multiply-reflected waves will thus be damped out at a shorter distance over land than over sea, and so in long-range direction-finding the night errors should disappear at a less distance for transmission over land than over sea.

This occurrence is to be distinguished from that in which freedom from errors is experienced when the transmission is entirely over sea for comparatively short distances—less than 100 miles. The experimental results obtained for this case were described in Section 4 (*c*), and the matter is referred to below from the theoretical point of view.

Case II. Error in Bearing is 90°

To obtain an apparent bearing which differs by 90° from the correct reading necessitates the value of β being negligible in comparison with that of α. There are two possibilities which might give rise to this case. The first entails the absence of a direct wave (h_o) and also that the incident wave is entirely horizontally polarised ($h_1 = 0$). These conditions are by no means impossible, although the writer has not personally experienced such a case.

The second possibility is one on which some very definite information has been obtained. With the reception of both direct and incident waves, it is necessary for the expression in equation (3)

$$h_0 \sin \omega t + h_1 (1 + \rho_v) \sin (\omega t + \chi_1)$$

to be zero in order that an error in bearing of 90° shall be observed. This implies that

$$h_0 \sin \omega t = - h_1 (1 + \rho_v) \sin (\omega t + \chi_1)$$

i.e.,
$$\chi_1 = (2n + 1)\pi$$

and
$$h_0 = h_1 (1 + \rho_v)$$

or in words, that the horizontal component of the vertically polarised incident wave is exactly equal and opposite to the direct wave.

Now in the case of observations of the apparent bearings of Bournemouth at Slough on a wave-length of 386 metres, an error of 90° was a frequent occurrence. From other and independent measurements carried out simultaneously[48], it was found that the angle of incidence of the downcoming waves was about 34°, and that the intensity of the horizontally polarised waves could be from 0·3 to 1·2 times that of the direct wave. Now at the

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frequency employed ρ_v is 0·9 for an angle of incidence of 34°; and thus $h_0 = 1{\cdot}9\ h_1$, *i.e.*, if h_1 were about 0·5 h_0, an error of 90° is completely explained. By actual measurement $h_1(1 + \rho_v)$ was found to be from 0·6 to 2·1 times h_0.

Case III. No Minimum is experienced on the Direction-Finder

This entails equality of magnitude of the two fields α and β with a 90° phase difference between them.

Thus advancing the phase of α in equation (2) by $\pi/2$

$$h_2(1 + \rho_h) \cos\theta \cos(\omega t + \chi_2) = h_0 \sin \omega t + h_1(1 + \rho_a) \sin(\omega t + \chi_1).$$

This phenomenon is of common occurrence on wave-lengths between 300 and 1,000 metres, and if the case of Bournemouth is again taken, it is seen that since, from experimental measurements,

h_2 lies between 0·3 and 1·2 times h_0
h_1 ,, 0·4 ,, 1·4 ,, ,,
θ ,, 16° and 34°

and ρ_h and ρ_v can have a value about 0·9 for these values of θ; then $h_2(1 + \rho_h) \cos\theta$ can have values between 4·7 h_0 and 2·2 h_0 and $h_0 + h_1(1 + \rho_v)$ can have values between 1·7 h_0 and 2·7 h_0. Hence the values of α and β overlap in the range 2·2 h_0 to 2·7 h_0; and it is therefore evident that with suitable phase relations the condition of " no minimum " on the direction-finder can be completely explained.

Case IV. Error in Bearing Not Greater than 45°

One of the facts that has emerged from the observation work on wave-lengths above 1,000 metres is that it is extremely rare for the apparent bearings to wander outside an arc of ± 45° about the true bearing. Now to get an error of 45° requires that $\alpha = \beta$, which is a condition similar to that of the previous case without the change of phase. That is, we have the equation

$$h_2(1 + \rho_h) \cos\alpha \sin(\omega t + \chi_2) = h_0 \sin \omega t + h_1(1 + \rho_v) \sin(\omega t + \chi_1).$$

If we imagine the magnitude of these two quantities to remain constant, and the phase of one of them to change from 0° to 180°, we shall have the resultant bearing error swinging from + 45° to − 45°, with an intermediate stage in which the signal minimum is indeterminate.

Each of the above cases *I* to *IV* may be complicated by the fact that instead of one set of downcoming waves of complex polarisation being received, these may be accompanied by other waves which have suffered two or more reflections from the ionised layer and which consequently arrive at a smaller angle of incidence than the once-reflected wave. Evidence of the existence of such

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multiply-deflected waves has already been obtained in experimental measurements.

Case V. Transmission Entirely Oversea

In concluding this section, one other case may be referred to, viz., that of the minimum distance at which bearing errors are experienced both over land and over sea. It has already been stated that no appreciable errors are experienced at distances of less than 30 miles over land, and it is believed to be true that the variations of received signal intensity are also small over such distances. These conditions evidently necessitate that h_1 and h_2 are small compared with h_0. Considering that at a distance of 30 miles and with a height of layer of 50 miles, the difference in path of the direct and indirect waves is over 74 miles, it is to be expected that the direct wave will predominate in intensity, especially when account is taken of the small reflection coefficient which will be operative for the indirect wave. Further, since over sea the attenuation of the direct wave will be much reduced, it is to be expected that the distance at which the indirect wave will begin to assume importance will be correspondingly increased.

This explanation of the greater range of freedom from directional errors was first suggested by Wright[57] in 1920. Up to the present time no accurate measurements of the relative attenuation of wireless waves travelling over land and sea are available, but calculations made from Sommerfeld's theory show that for a wave-length of 300 metres the intensity of a wave travelling 150 km. over land would be less than one-tenth of the intensity obtained over sea at the same distance.

In the above treatment the problem of direction-finding has been dealt with on broad lines with a view to showing that the theoretical explanation of night errors in direction-finding is quite sound when examined from the quantitative point of view with the aid of the data now available. It is evident that the further contribution which directional measurements are likely to make to the study of the problem of the propagation of wireless waves is extremely small, since such measurements at the best merely give the ratio of two quantities, each of which contains two or more variables. The way to further progress lies rather in the use of methods of measuring the individual quantities, such as α, β and γ, which combine to produce the resultant field at the receiver; and this line of action has already been inaugurated and is being actively pursued.

It will be evident that throughout this discussion no mention has been made of the mechanism of the ionised layer which causes the deflection of the waves, and particularly of that which results in the erratic and peculiar variations experienced. As the result of intensive research being carried out in various parts of the world on the propagation of electromagnetic waves, the mechanism of the actual deflection is being put on a satisfactory quantitative basis.

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6. The Elimination of Night Errors

It is evident from the discussion in the last section that the night errors experienced in the use of closed-coil direction finders are due to the action of the horizontally polarised component of the downcoming waves, *i.e.*, the field component α. Any receiving system which was unaffected by this component would be free from such night errors, even though the vertically polarised downcoming waves might still produce variations of received signal strength. It is generally assumed that the downcoming waves have travelled via the upper regions of the earth's atmosphere without deviating laterally from the great-circle plane through the transmitter and receiver. This assumption has, however, not been sufficiently well justified in the past, and the presence of the downcoming waves has hitherto made it difficult to prove whether the direct waves travelling along the earth's surface have also suffered lateral deviation. With a view to ascertaining to what extent, if any, such lateral deviation exists, several directional receiving arrangements have been examined, both theoretically and experimentally. After overcoming some difficulties on the experimental side, success was attained with the direction-finding system patented in 1919 by F. Adcock[1]. This system employs the equivalent of a pair of spaced vertical aerials arranged to rotate about a central vertical axis. All the horizontal members of the system are compensated so that no E.M.F. is induced in the system by the horizontal electric fields which cause the errors in apparent bearing on the ordinary direction-finder. The development of this system for the present objects, and the results of some experiments carried out with its aid, have been described in a previous paper[51]. The type of result obtained is illustrated by the curves given in Fig. 15, which shows the results of simultaneous observations made on an ordinary single-coil direction-finder and on one of the Adcock type. It will be seen from this diagram that, while the single-coil set during this particular period of observations was giving very bad night variations, the corresponding errors observed on the Adcock direction-finder were negligible. It is to be concluded from these and similar results obtained on the transmissions from other broadcasting stations that lateral deviation plays a negligible part in producing the large and variable errors in apparent bearings which are obtained at night on the present type of closed-coil direction-finding set, and that, therefore, these errors are entirely caused by the arrival of downcoming waves polarised with the electric force horizontal.

It will be appreciated that it follows from the above conclusions that such a system may be used as a direction-finder which gives the true great-circle plane of arrival of wireless waves, whatever may be their state of polarisation or their angle of incidence relative to the earth's surface. The system should, therefore, have important applications as an accurate direction-finder

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under night conditions, or for use in observing on transmissions from aircraft at high angles of elevation, when the ordinary closed-loop type of instrument is subject to such large errors as to make it practically useless. The practical development of the instrument towards this end is now being pursued.

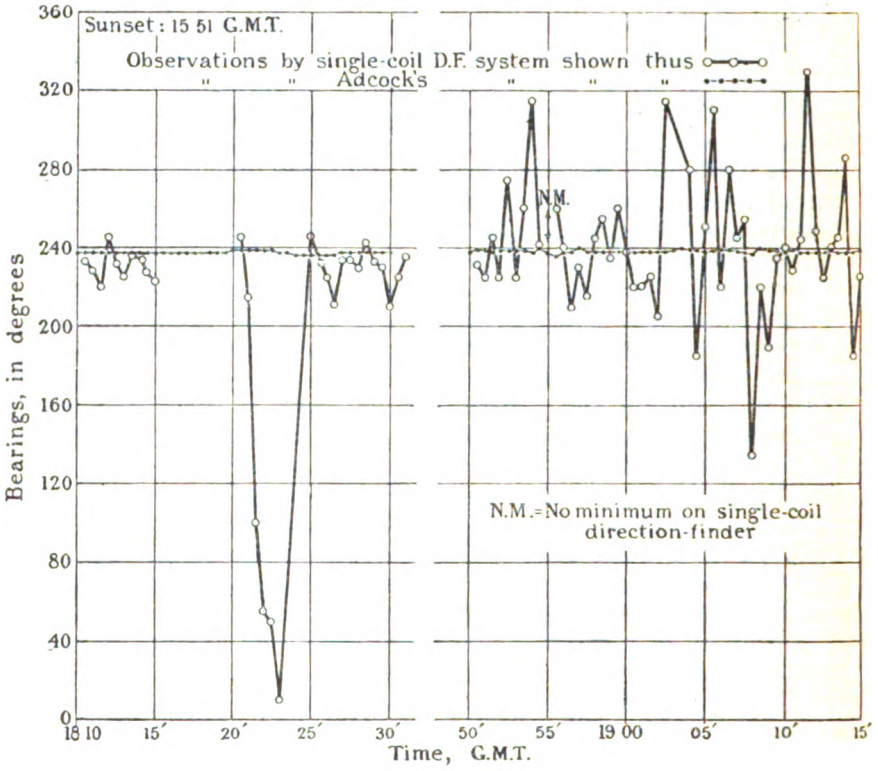

FIG. 15.—*Observations of Bearings on Bournemouth, December* 10, 1925 ($\lambda = 386$ m.), *taken simultaneously at Slough on a closed-loop and on an Adcock direction-finder.*

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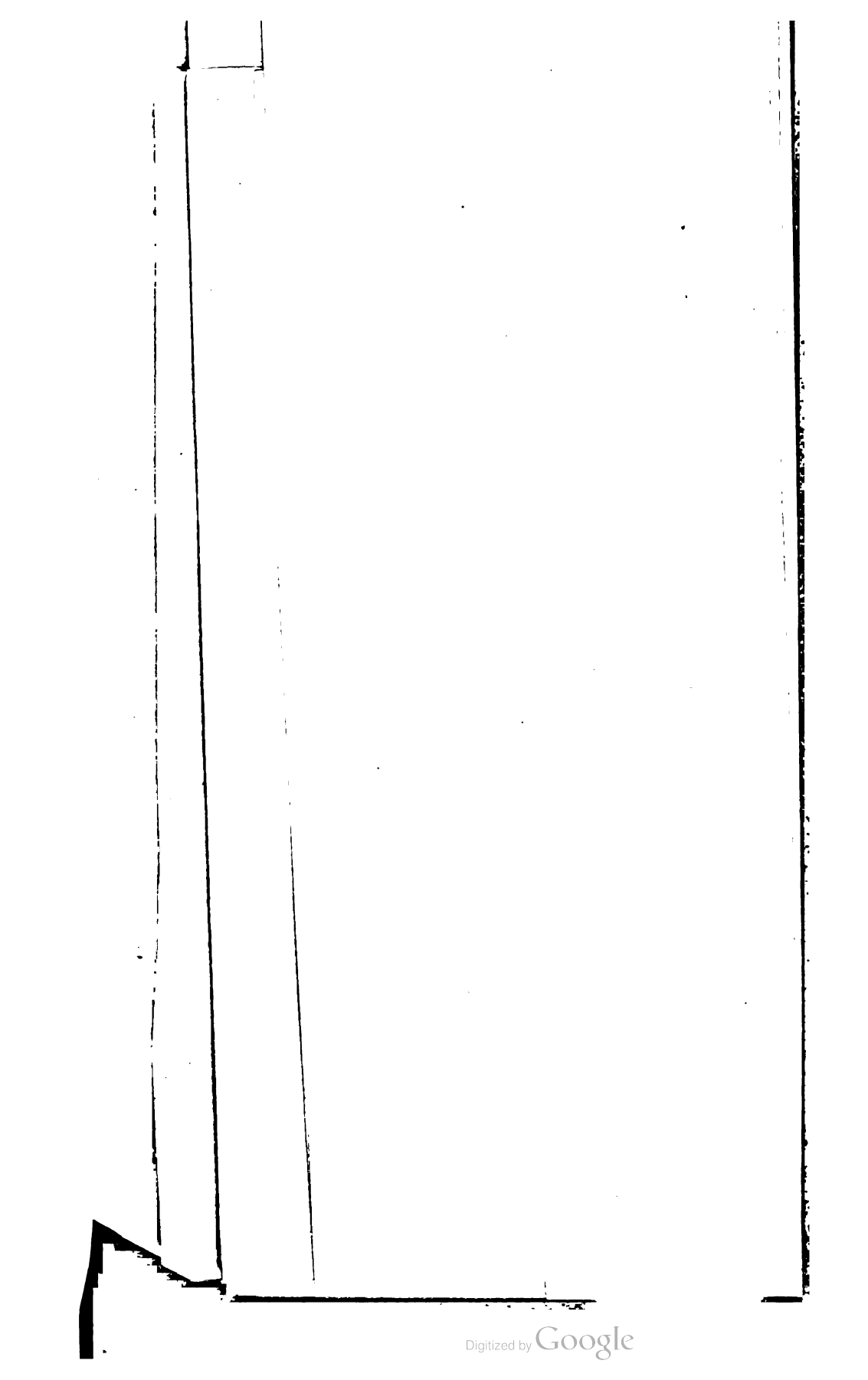
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View of Rotating Beacon, inside hut, Fort Monckton, 1926.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

RADIO RESEARCH

SPECIAL REPORT No. 6

AN INVESTIGATION OF A ROTATING RADIO BEACON

BY

R. L. SMITH-ROSE, D.Sc., Ph.D., A.M.I.E.E.,

AND

S. R. CHAPMAN, M.Sc., A.M.I.E.E.

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INTRODUCTORY NOTE

THIS report describes experiments carried out on a rotating loop beacon transmitter erected at Fort Monckton, near Gosport. The beacon was identical with the type already in use by the Air Ministry, and the object of the present investigation was to study the performance of the beacon when transmitting over land and sea, and particularly to ascertain the reliability, for marine navigation purposes, of wireless bearings taken with the aid of the beacon under a variety of conditions.

As a result of a series of observations carried out in ships under sea-going conditions, it has been found that the rotating loop beacon can give reliable bearings of the same order of accuracy as that obtainable in wireless direction-finding under the most favourable conditions. With the beacon at Fort Monckton the reliable working range was over 50 miles by day and night, at which distance the majority of observed bearings were correct within 2°; certain effects due to the waves passing over land were encountered and investigated, with the result that it was found desirable, though not essential during the day, for the path of transmission to be entirely over sea.

A great advantage possessed by this system is that it requires only an ordinary wireless receiver and a suitable watch to enable a ship to take bearings, and it is therefore likely that the system will prove of considerable value in the application of wireless to marine navigation.

The site at Fort Monckton was made available by the War Office, and, as explained in the report, the beacon was designed and erected for the Department by the Air Ministry. The Admiralty also co-operated in the investigations, both by the loan of certain equipment, including the supply of the tuning-fork control apparatus installed at the beacon, and by providing the additional personnel necessary for running the beacon during

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some of the prolonged tests. Acknowledgments are also due to the Southern Railway Company, and to the Marconi International Marine Communication Company, without whose assistance a large portion of the work over sea could not have been accomplished.

F. E. SMITH
(*Chairman of the Committee on Directional Wireless*).

December, 1927.

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AN INVESTIGATION OF A ROTATING RADIO BEACON

1. Historical

THE application of radio signalling as an aid to navigation depends essentially upon the use of apparatus whose radiating or reception properties are dependent upon the orientation of some component relative to the waves. The radio direction-finder as a means for determining the direction of a distant transmitting station has been developed to a high degree and has now a well-established place in the arts of both air and marine navigation. As an alternative the directional property can be transferred to the transmitting station, so that its direction can be determined at a distant receiving station by the aid of some characteristic of the emitted radiation.

Both of the types of directional systems which are in use to-day may be said to date from the time of Hertz, since in his experimental researches Hertz used reflectors to concentrate the radiation from a straight rod aerial, and also loops whose transmission or reception properties depend upon the orientation of the loop. Of recent years the properties of reflecting systems used in conjunction with linear aerials have been studied by Franklin ; [1]* and others,[2] and with the application of the beam system to long-distance communication considerable development has been taking place in many countries. The beam system has also beem adapted as a rotating beacon transmitter,[3] but practical limitations necessitate its operation on the very low wave-lengths of 6 to 10 metres. Experimental beacons of this type have been installed at Inchkeith[1] and South Foreland,[3] but it is believed that its use among ships has not been very widespread.

The predecessor of the closed loop antenna, whether for reception or transmission, is to be found in either the inverted L aerial or in a pair of spaced vertical aerials.

The former has developed into the Beverage aerial, which is now used as one method of obtaining directional selectivity at the receiving end. A system of inverted L aerials giving directional transmission has been experimented with by Scheller, Buchwald[4] and Kiebitz.[5] For navigation purposes it is also probable that the Telefunken compass[6] arrangement falls under this heading. This system made use of a series of directional aerials radiating from a central mast, these aerials being excited in turn by a rotary switch operating at a speed of one revolution per minute. A non-directional aerial was also provided for the

* These numbers refer to the Bibliography on page 34.

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purpose of transmitting a timing signal applicable to the directive system. By noting the interval between this time signal and the reception of the signal from the directional system, the bearing of the transmitter could be estimated from a distant receiver.

The combination of the pair of spaced aerials developed first into the Bellini-Tosi system of direction-finding, and later into the rotating frame coil. The transmitting equivalent of the Bellini-Tosi direction-finder is to be found in the Radiophare, several of which were in operation on the French coast prior to 1914. In the same manner the single frame coil can be adapted to transmission, since its polar radiation characteristic is the well-known figure-of-eight diagram, and thus the intensity of the radiation varies according to a cosine law with the angle between the plane of the loop and the direction of transmission. One of the great advantages of a loop transmitter is that it can be operated on the wave-lengths usually employed in ship and aircraft wireless communication.

Various methods of applying the rotating loop transmitter for navigation purposes were described by Erskine-Murray and Robinson[7] in 1922, while among others who have investigated this subject may be mentioned Engel and Dunmore[8] in America, and Kiebitz[9] and Scheller in Germany.

The rotating beacon system which has been developed to a high degree in this country by the Royal Air Force,* and which is the subject of investigation in the following paper, makes use of a vertical closed loop rotating about a vertical axis at a uniform speed of 1 revolution per minute. When the plane of the coil is perpendicular to the geographical meridian a characteristic signal is emitted by the beacon which may be termed the N. point. An observer at a distant receiving station upon hearing this signal starts a chronograph. As the beacon rotates the intensity of the received signal varies and will ultimately pass through a minimum or zero value, at which instant it is known that the plane of the transmitting loop is at right angles to the great circle joining transmitter and receiver. If the reading of the chronograph is observed at this instant of minimum signal intensity, it is evident that the bearing of the transmitter from the receiver can be obtained by a simple calculation. To provide for the case in which the observer is due north or south of the beacon, when the N. signal would probably be inaudible, another characteristic signal is emitted after a 90° rotation to the corresponding E. point. Bearings observed from this signal as a starting-point are evidently subject to a correction of 90°. It is to be noted that since the radiation from the coil is symmetrical about its plane, a second minimum will be obtained after a rotation of 180° from the first. With the beacon making one revolution per minute, therefore, a line bearing is obtainable in the above

* Since this Report was written a paper describing the development of the rotating beacon has been published by T. H. Gill and N. F. S. Hecht: "Rotating-Loop Radio Transmitters and their application to Direction Finding and Navigation." *J. Inst. Elec. Eng.*, 1928, **66**, 241.

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manner every half-minute. To fix the position of a receiving station it is necessary to obtain line bearings in this manner from two or more beacons.

2. General

(*a*) *Installation of the beacon*

With the object of examining the performance of this type of beacon, particularly from the standpoint of its utility to shipping and marine navigation, an experimental beacon station was set up for the Department of Scientific and Industrial Research by the Air Ministry at Fort Monckton, near Gosport, in July, 1926. The installation comprised a rotating loop valve transmitter, which was similar in design and construction to that previously in operation at the Royal Aircraft Establishment, Farnborough.

The accuracy of the bearing observations obtained with this system of directional wireless depends essentially upon two features; first, the quality of the zeros or signal minima, and, second, the uniformity of the time of rotation. Since the estimated bearing depends directly upon the observation of the time of occurrence of the signal minimum, the rate of change of signal strength should be very large at this position of the transmitter, or in other words, the signal zero or minimum should be as sharp and well-defined as possible. Various spurious effects, both in the wireless transmitter itself and external to it, tend to mitigate against the production of really sharp signal zeros, and the discussion of these with possible modes of improvement is given later in the report.

(*b*) *Improvement of the time of rotation*

The time of rotation of the beacon is intended to be 60 seconds, and it should be as uniform as possible so that it will be known that in each tenth of a second the beacon has turned through 0·6°.

When the beacon was first installed at Fort Monckton, the motor driving the transmitting coil was operated direct from the local electrical supply mains. Owing to the large variation in the supply voltage experienced, however, a small 50-volt battery was later installed to give a constant voltage supply to the driving motor. While this effected a considerable improvement in obtaining uniform running of the beacon, it was still not easy to maintain, by manual control, the time of rotation constant to within 0·2 second. Accordingly, with the assistance of the Admiralty Research Laboratory, Teddington, a phonic motor, operated from an electrically maintained tuning-fork, was fitted to control the speed of the driving motor. The tuning-fork is adjusted to vibrate at 50 cycles per second at the mean temperature of the beacon room, and the phonic motor running at 300 revolutions per minute is geared to the central shaft so that the beacon makes exactly one rotation per minute. This speed is maintained accurately constant and uniform, provided that the main driving motor is set to run at *approximately* the correct

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speed. To give an instantaneous indication of the speed, the flywheel of the phonic motor is used as a stroboscopic disc illuminated intermittently by a Neon lamp, also operated from the tuning-fork. In the course of an ordinary three-hour run, with the beacon starting from rest, there is usually a slight drift in the speed of the driving motor, due to the slow but definite drop in the voltage of the supply battery and the gradual warming-up of the gears and bearings. This drift in speed is indicated immediately by the stroboscopic attachment mentioned above, and it is found that it can be completely counteracted by a slight adjustment of the control resistances at intervals of not less than fifteen minutes. The above arrangement provides a uniformity of rotation which is beyond the limits of timing provided by the ordinary chronograph or stop-watch. By timing it against an accurate chronometer over periods of an hour or more, it can be shown that the time of rotation is uniform and accurate to within one-sixtieth of a second per minute at an even room temperature. The tuning-fork is subject to a temperature variation of about 10^{-4} per 1° C., and the speed of the beacon will, of course, follow suit. Even so, however, a variation of the temperature of $\pm$ 16° C. would only produce a variation in time of rotation of one-tenth of a second, which is beyond the limits of reliability of the stop-watch timing method. Even this slight variation could be eliminated, if necessary, by placing the tuning-fork in a thermostatically controlled box, or by the use of " Elinvar " in the construction of the fork.

(*c*) *Watch and personal errors*

In connexion with this section, it may be mentioned that the best type of 60-seconds chronograph has given errors of $\pm$ 0·3 second when used for timing the beacon with skilled observers. This error has been definitely traced to a combination of watch and personal error, and is independent of the beacon. It is thus evident that, due to the method of timing adopted, a maximum error of $\pm$ 2° is liable to appear in the recorded observations, and this would appear to represent the limiting accuracy of this system of directional wireless for individual readings. By taking the mean of a series of successive readings this error can, of course, be materially reduced. As a later development it may be found convenient to run the beacon at a slower speed of say 1 revolution in two minutes.

In concluding this section it may be mentioned that since there is now no point in timing the rotation of the beacon, the chronograph used by the observer may be provided with a dial marked off as a compass card, as shown in Figs. 8–11 in Appendix 1 of this report. If the watch is started on the N. signal, then the position of the hand at the minimum signal indicates the bearing of the transmitter directly. The watch can, if necessary, be provided with adjustable scales to provide for working from the E. point, and the scale can also be arranged to suit any other time of rotation. (See Appendix 1.)

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(d) Quality of signal minima and effect of local conditions

As first installed, the beacon at Gosport emitted a signal which possessed two characteristics which made it difficult to take bearings of the highest accuracy. In the first case the signal minima given by the beacon were unequal in quality, one being usually quite silent and fairly sharp, while the other was not silent and was of approximately constant intensity for about one second. This characteristic is well illustrated by the polar

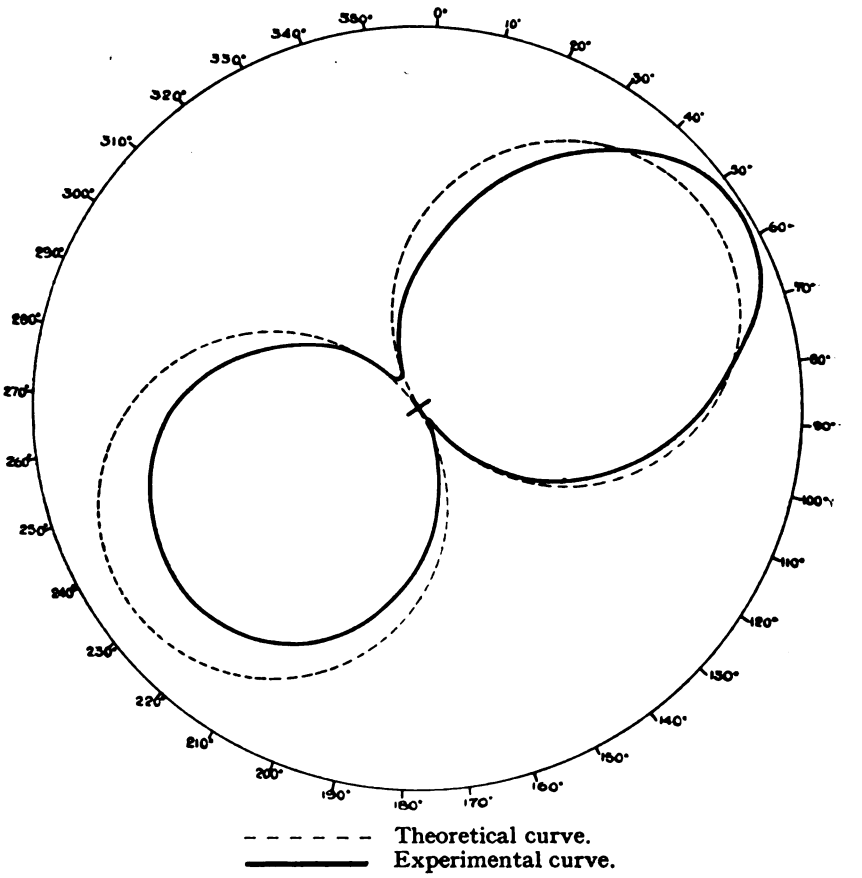

FIG. 1.—*Polar Radiation Curve for Fort Monckton Rotating Beacon. Transmitter—5A Y—measured near Stubbington. Distance* 4·6 *miles. Bearing* 139 5°.

curve shown in Fig. 1, which is the result of an experimental measurement made at a distance of 4·6 miles from the beacon. The difference in quality of the signal minima are to be noted, and in addition the difference in magnitude of the maximum signal intensities. The other characteristic possessed by the signal was that during the rotation of the beacon the wave-length altered slightly in a fairly regular cycle. This wave-length

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change was small and was of no consequence for interrupted continuous-wave transmission. When continuous waves were employed, however, and reception was by the heterodyne method, the received beat note varied in pitch over a range of about 400 cycles during each revolution, and this variation made it difficult to take observations to the highest accuracy. With a view to improving these two defects, certain experiments have been carried out at Gosport, and although these have not been successful in removing the defects, they have provided some definite knowledge as to the effect of certain local conditions on beacon transmitters.

In the first instance, all overhead telephone and electric-light wires within a radius of 30 yards of the beacon were removed or placed underground, but no effect was noticed on the quality of the signal received from the beacon. Certain small receiving aerials in the immediate locality were removed, but there remained the electric-light wiring of neighbouring buildings and also the metal guys to a mast 85 feet high at a naval signal station about 45 yards distant. The effect of overhead aerials on the polar radiation characteristics of a rotating loop transmitter has been studied theoretically, and an outline of the analysis is given in Appendix 2 of this report. It is to be concluded from this that within a radius of 100 yards an open aerial, unless of very large dimensions, will not appreciably affect the radiation from a beacon of the type under investigation. To check the results of this deduction an experiment was carried out in which a single-wire aerial, 150 feet long, was erected near the beacon. The aerial was supported from a neighbouring mast at a maximum height of 60 feet, and sloped towards the ground near the beacon, the minimum distance from the aerial to the beacon loop being 36 feet. When this aerial was tuned the maximum current induced therein by the beacon transmitter was about 18 milli-amperes when provided with a very poor earth connexion. Various tests were made at two receiving stations as to the effect of tuning and detuning this aerial on the bearings observed by rotation of the beacon. The results show that the maximum error produced due to the presence of this aerial was less than 1°, which agrees with the theoretical prediction, while no marked effect was observed on the quality of the signal minima. The provision of a much better earthing arrangement, a larger aerial, or closer proximity to the transmitter would, of course, have rapidly brought on serious errors, but this experiment was considered sufficient to demonstrate that the surrounding overhead wiring, mast stays, etc., in the neighbourhood of the beacon at Fort Monckton were not the major cause of the defects in the quality of the radiation characteristics.

The next experiments were connected with the effect of various screening arrangements on the radiation. It was thought that the variation in wave-length described above might be due to some asymmetry in the capacity to earth of the oscillating circuit during the rotation of the loop. (It may be mentioned that the

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observed change in wave-length required a variation of capacity of less than one part in a thousand during rotation, and so might easily arise in the construction or installation of the beacon). In the first case, the whole of the transmitter room below the rotating loop, was enclosed in a cage of wire netting of one-inch mesh. As certain losses were experienced in the top of this due to its proximity (18 inches) to the lower side of the rotating loop, a hole about 9 feet in diameter was subsequently made in this cage. The existence of this cage produced little or no effect on the signals received. Next the screen was continued up over the top of the beacon with a series of open wire loops broken at the top with insulators, and arranged in the form of a vertical cylinder, 9 feet in diameter and with 36 wires 15 inches apart at the base. This screen should have the effect of preventing any " vertical aerial " effect in the radiation from the transmitter, and its presence produced the immediate effect of equalising the quality of the two signal minima. The sharpness of the better minimum was somewhat decreased, but the quality of the other was considerably improved. As the overall effect was considered to be an improvement, this screen has been left in position throughout the remainder of the tests and experiments on the beacon. No marked effect on the variation of wave-length during rotation was observed. The results of some further experiments carried out since writing this report are given in Appendix 3.

Further experiments were carried out on the effect of connecting the centre point of the rotating loop to the screen and to earth, and on the use of condensers between either end of the loop and earth, with a view to making the oscillating circuit more symmetrical. None of the several tests carried out, however, produced any noticeable effect on the signals observed at two receiving stations, one being situated within 5 miles, and the other at about 55 miles from the beacon.

The net result of the above experiments shows that, with the exception of the effect of the open wire screen, the radiation from the rotating loop is largely immune from the effects of any existing metal wiring and from small adjustments in the transmitter circuit itself. This leaves open the question of site, and as to whether the fact that the Gosport beacon is erected on the boundary between land and sea, with a sheer drop of about 25 feet, is the cause of the imperfect minima and the variation of wave-length during rotation. This point cannot be definitely settled until the opportunity is provided for examining the performance of a similar beacon erected upon an improved site. It is possible that the influence of the site at Gosport has masked any effect produced by the various changes described above, and that these tests would require repetition on a more favourable site.

3. Calibration of the Beacon over Sea and Land

This has consisted in testing the accuracy of the observed bearings of the beacon over a short period of from one-half to

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one hour in daylight in various directions and at distances ranging from 1·6 to 55 miles. The observations were made at carefully selected points from which the true bearing of the beacon was easily obtained. Many of these are indicated on the chart in Fig. 2, which illustrates the surroundings of Fort Monckton. At sea these points comprised the various Forts, Light Vessels, and Buoys within range; while on land, the points were ranged along the circumferences of three circles of approximately five, fifteen, and fifty miles radius with the beacon at the centre. This work was first carried out from July to October, 1926, and at most of the sites the observations were repeated on a second and third occasion after an interval of from one to four weeks. The mean bearings obtained on these separate occasions usually agreed to within one or two degrees, although in a series of from 6 to 20 consecutive observations made on any one occasion, the individual readings differed from the mean by amounts ranging up to five degrees.

A large number of the sites were revisited after a period exceeding seven months, and the observations repeated during May to September, 1927. Additional positions were also employed in this later work, and the results obtained serve to confirm and extend the conclusions drawn from the former tests. A summary of all the observations made during the latter period is given in Table 1, and from this is plotted the graph shown in Fig. 3, which has been used as a working calibration curve from which observed bearings taken on the beacon in any direction can be corrected.

This curve and the results in Table 1 show that the mean bearing as observed in the above manner differs from the true bearing for each position by amounts ranging up to about eight degrees. Although this difference includes the error of observation and the error of obtaining the true bearing from charts, a little consideration will show that the bulk of this error is due to some land deviation effect produced at the coastal boundaries. In the first place if the transmission path is uniform, either land or water, the above error does not alter appreciably with the distance of the point of observation, but is associated chiefly with the direction of transmission. Secondly, the error is limited to one or two degrees in the small open sea sector (approximately 120° to 170°) available from the Fort Monckton beacon. Thirdly, in the sector occupied by the Isle of Wight the error varies in an irregular manner and depends upon which side of the island the observations are made. Furthermore, with the exception of the Isle of Wight the error varies in a moderately regular manner with the direction of transmission. There appear to be two lines of zero error radiating in directions 310° and 50° from the beacon, the error being subject to a change in sign as these directions are crossed. In comparison with this error the effect of conditions such as trees, wires, etc., local to the receiver are of minor importance. For example, at one point an error of 9° was obtained at a distance of 100 yards from a straight stretch of overhead wires over three miles long. On moving the receiver to a distance of

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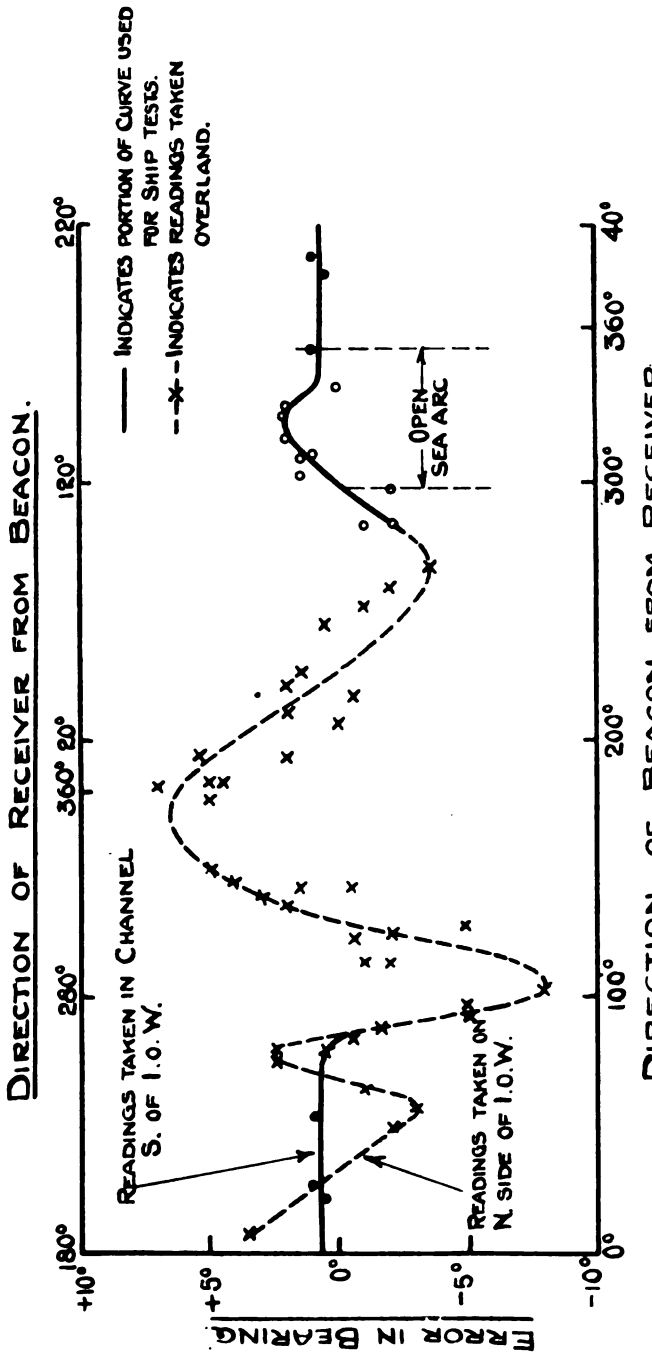

FIG. 3.—*Calibration Curve of Fort Monckton Rotating Beacon. May to September*, 1927. ($\lambda = 525$ *metres.*)

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1,300 yards from the wires, the error was found to have decreased by 1° only.

The constancy of this calibration has been checked by taking bearing observations on the beacon in daylight on from two to

TABLE 1. *Summary of Results obtained in the Calibration of Fort Monckton* (5*AY*) *at Fixed Points*, 1927

Position.	Fort Monckton.		Error in observed bearing.	Remarks.
	Distance.	Bearing.		
	miles.	degrees.	degrees.	
Sturbridge Buoy ..	2·2	7·0	+3·5	Across Gilkicker Point.
Jersey	119·0	21·0	+0·5	Across Isle of Wight.
St. Catherine's Pt.	15·5	27·5	+1·0	
Fishbourne ..	4·5	49·0	−2·0	On Isle of Wight.
Brighstone Down ..	13·9	53·0	+1·0	Across Isle of Wight.
Wootton	5·1	57·0	−3·0	On Isle of Wight.
Bouldnor Cliff ..	14·3	73·5	−1·0	On Isle of Wight.
Ryde, Middle S.E.	3·3	74·5	+2·5	Across Gilkicker Point.
Solent Banks ..	13·6	79·0	+0·5	Across Gilkicker Point and I.O.W.
Lulworth	48·9	79·5	+2·5	
Barton	23·3	83·5	−0·5	
Tanner's Lane ..	15·4	85·0	−0·5	
East Lepe Buoy ..	9·5	88·0	−1·5	
Stone Point ..	9·4	94·0	−5·0	
Beaulieu Rails ..	15·0	95·0	−5·0	
Picket-Post ..	26·5	102·0	−8·0	
Blackjack Buoy ..	7·7	113·5	−2·0	
Dibden Bottom ..	14·8	113·5	−1·0	
Hillhead	4·9	122·0	−0·5	
Hamble Common ..	9·5	124·5	−2·0	
Southampton Dock	14·3	127·5	−5·0	
Romsey	21·6	136·0	+2·0	
Stubbington ..	4·9	139·5	+3·0	
Swanwick	9·6	141·5	−0·5	
Eastleigh	15·5	142·0	+1·5	
Caiger's Green ..	9·8	144·5	+4·0	
Horton Heath ..	14·3	149·5	+5·0	
Porchester	5·0	178·0	+5·0	
Exton	14·7	182·5	+7·0	
Purley-on-Thames	48·2	183·5	+4·5	
Purley-on-Thames	48·8	184·5	+5·0	
Twyford	50·1	194·0	+2·0	
Faringdon	24·2	194·5	+5·5	
Slough	55·0	207·0	0·0	
Cosham	5·1	211·0	+2·0	
Teddington ..	56·5	218·0	−0·5	
Compton Park ..	14·8	222·0	+2·0	
Emsworth Common	10·4	227·5	+1·5	
Nutbourne ..	11·4	244·5	+0·5	
E. Ashling	14·5	244·5	+0·5	
Fort Cumberland ..	4·7	253·5	−1·0	
Appledram ..	14·7	260·0	−2·0	

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TABLE 1—*continued*

Position.	Fort Monckton.		Error in observed bearing.	Remarks.
	Distance. miles.	Bearing. degrees.	degrees.	
Southsea Pier ..	2·5	267·5	−3·5	Open Sea.
Selsey Bill	14·8	282·5	−2·0	
Spit Fort	1·6	283·0	−1·0	
Owers Light V. ..	22·3	298·0	−2·0	
Horse Sand Fort ..	3·2	303·0	+1·5	
Nab Tower ..	10·8	309·0	+1·5	
Fécamp	92·0	312·0	+1·0	
Warner Light V. ..	4·4	317·5	+2·0	
Nomans Land Fort	3·0	325·0	+2·0	
Havre Quay ..	105·0	328·0	+2·0	
Bembridge ..	6·5	337·0	0·0	
Seaview	3·7	351·0	+1·0	

five days per week over a period of six months. These observations have been carried out at the National Physical Laboratory, Teddington, and the Radio Research Station, Slough, and also by Sir Henry Jackson at Westminster. The results have been collected in weekly batches, and a summary of them is given in Table 2.

TABLE 2. *Summary of Day Observations on the Rotating Beacon taken from April to September,* 1927

Position.	Fort Monckton.		Number of observations.	Mean bearing.	Error of mean bearing.	Variation.		Type of transmission.
	Distance. miles.	Bearing. degrees.		degrees.	degrees.	Extent of. degrees.	Extreme from mean. degrees.	
Slough ..	55·0	207	657	208	+1·0	6·6	+3·4	C.W.
,, ..	55·0	207	156	208	+1·0	4·2	+2·3	I.C.W.
Teddington	56·5	218	2,154	217	−1·0	4·2	±2·1	C.W.
,,	56·5	218	251	217	−1·0	4·8	−2·5	I.C.W.
Westminster	66·5	221	472	219	−2·0	9·0	+5·0	C.W.
,,	66·5	221	58	220	−1·0	4·8	−2·7	I.C.W.

It is seen from these results that over the whole period the maximum deviation from the mean bearing ranges from 2° to 5°; it is in fact, of the same order as the deviations normally experienced in a day's observations. There is thus no evidence of a

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seasonal change in the bearings observed on the rotating beacon from fixed receiving stations.

In the work carried out at sea, described in the following Section, the latest calibration, as determined during the current year, has been utilised in applying corrections to bearings observed on the beacon.

4. Tests carried out in Ships

As one of the principal objects for conducting this investigation was to ascertain the reliability of the rotating beacon as an aid to marine navigation, some considerable time has been spent in carrying out experiments in ships at sea. With the kind assistance of the Southern Railway Company a number of trips have been made in that Company's ships between Southampton and Havre, and Southampton and Jersey. Further trials on board H.M.S. *Truant* have also been carried out with the co-operation of H.M. Signal School. The portion of the English Channel in which these tests were made is shown in the chart forming Fig. 4.

Using the ship's ordinary wireless receiver, observations of the bearing of the Fort Monckton beacon were made at intervals during each trip and compared with the bearing as given by the Captain of the ship. In all cases the wireless bearings were taken by skilled observers, as it was not thought desirable at this stage to introduce any personal errors which might be associated with the various ship's operators. The bearing given by the Captain was usually obtained by dead-reckoning, although it was checked by visual observations when possible. The results obtained on the three routes may be briefly summarised as follows :

(*a*) *Southampton to Havre*

On this route the transmission path from the beacon to the ship is entirely oversea and of almost constant bearing from the time the ship passes the Nab Tower until its entry to Havre. The difference between the wireless bearing and the bearing obtained from the ship's position by dead reckoning has ranged up to 9° on the various trips, but in the majority of cases these bearings have agreed to within 2°. As will be explained below there is good reason to expect that in many of these cases the wireless bearing is the more accurate, and that the larger differences are due to incorrect estimation of the ship's position. Summaries of the results obtained on two of these trips are given in Tables 3 and 4, while a plot of the results obtained on a third run is shown in Fig. 4. All these runs were carried out at night, and so should indicate the worst conditions from the wireless point of view. Referring to the Tables 3 and 4, it is seen that the maximum difference between estimated and observed bearings is 4°, and that in 33 cases out of the 42 cases observed this difference was within 2°. It is also to be noted that at distances of 60 miles

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and over night effect was observed on several occasions in the shape of a blurring of the signal minima and a tendency of successive bearings to wander erratically. The existence of this night effect, however, did not appear to influence greatly the accuracy of the bearings, since the larger differences occur at various ranges from 24 miles upwards. (Compare Fig. 4.)

TABLE 3. *Summary of Observations obtained on a Return Voyage from Southampton to Havre, September 22nd to 24th*, 1926

Continuous Wave Transmission, 525 metres

Date, Sept., 1926.	G.M.T.	From information supplied by Captain of ship.			Wireless bearing from Beacon.
		Position and how obtained.	From Fort Monckton.		
			Distance. miles.	Bearing. degrees.	degrees.
22nd ..	2240	Southampton A ..	14·3	127	126*
23rd ..	0102	Beyond Nab V.B. ..	17·5	324	323
	0132	D.R. ..	26·0	328	329
	0202	D.R. ..	35·0	330	331
	0232	D.R. ..	43·0	331	331
	0302	D.R. ..	51·0	332	332
	0332	D.R. ..	60·0	333	334
	0532	D.R. ..	85·0	335	335
	0602	D.R. ..	94·0	334	335†
	0632	D.R. ..	96·0	330	331†
	0722	Havre A ..	105·0	328	330
	1702	,, A ..	105·0	328	329*
24th ..	0012	D.R. ..	95·0	330	331
	0032	D.R. ..	88·0	330	329†
	0102	D.R. ..	79·0	329	327†
	0132	D.R. ..	69·0	329	325
	0202	D.R. ..	60·0	329	325†
	0232	D.R. ..	52·0	329	325
	0402	D.R. ..	24·0	329	326
	0432	V.B. ..	15·0	325	326
	0442	2 mls. from Nab .. V.B. ..	11·5	324	323

* Mean of several readings.

† Night effect observed.

NOTES.

1. A = moored in dock. V.B. = visual bearings. D.R. = dead reckoning.
2. Night effect observed at 60 miles and over.
3. Maximum difference between estimated and observed bearings = 4° at night.
4. Sea moderate throughout.

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TABLE 4.—*Summary of Observations obtained on a Return Voyage from Southampton to Havre, August 6th to 9th, 1927*

Date, Aug., 1927.	G.M.T.	From information supplied by Captain of ship. Position and how obtained.	From Fort Monckton. Distance. miles.	From Fort Monckton. Bearing. degrees.	Wireless bearing from Beacon. degrees.	Type of transmission.
6th ..	2151	Southampton Dk. A. ..	14·3	127	126	I.C.W.
7th ..	0012	West of Nab V.B...	11·5	319	319	C.W.
	0105	D.R...	29·0	328	329	C.W.
	0135	D.R...	39·0	329	332	C.W.
	0205	D.R...	49·0	331	331	C.W.
	0335	D.R...	71·0	332	331	C.W.
	0405	D.R...	81·0	331	334	C.W.
	0435	D.R...	91·0	330	331	C.W.
	0447	Nr. Cape La Héve V.B...	96·0	330	334	I.C.W.
	1638	Havre A. ..	105·0	328	328*	C.W.
	1651	,, A. ..	105·0	328	328*	I.C.W.
8th ..	0848	,, A. ..	105·0	328	328*	I.C.W.
	0933	,, A. ..	105·0	328	329*	C.W.
	2302	Cape La Héve V.B...	98·0	330	331	C.W.
	2335	D.R...	90·0	330	331	C.W.
9th ..	0005	D.R...	81·0	329	325†	C.W.
	0035	D.R...	71·0	329	331	C.W.
	0105	D.R...	61·0	329	333	C.W.
	0335	D.R...	16·0	323	324	C.W.
	0349	West of Nab V.B...	11·5	319	319	I.C.W.
	0535	Southampton Dk. A. ..	14·3	127	126	C.W.

* Mean of several readings.

† Night effect observed.

NOTES.

1. A = moored in dock. V.B. = visual bearings. D.R. = dead reckoning.
2. Night effect observed at 80 miles.
3. Maximum difference between estimated and observed bearings = 4° at night.
4. Sea moderate throughout.

(*b*) *Portsmouth to Fécamp*

A record of another test made in the open-sea arc from Fort Monckton is given in Table 5, which is a summary of the results obtained on board H.M.S. *Truant* on a trip from Portsmouth to Fécamp (see Fig. 4) and back to Owers Light Vessel. In this case both trips were made in daylight and, with only a moderate sea, the conditions were very favourable from the wireless standpoint. On both occasions, however, the atmosphere was misty, rendering visibility very poor and necessitating the navigation of the ship by dead-reckoning only. Under these conditions

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it is seen that the difference between estimated and observed bearings attains a maximum value of 5°. Comparing these results with those discussed above, it appears that within the area covered by these tests the differences in these bearings by night are only slightly in excess of those recorded in the daytime. It is also to be observed from Table 5 that on continuous-wave transmission the results are similar to those obtained with interrupted continuous-wave transmission.

TABLE 5. *Summary of Observations obtained on a Voyage from Portsmouth to Fécamp, and from Fécamp to Owers Light Vessel, August 29th to 31st, 1927*

Date, Aug., 1927.	G.M.T.	From information supplied by Captain of ship. Position and how obtained.	From Fort Monckton. Distance. miles.	From Fort Monckton. Bearing. degrees.	Wireless bearing from Beacon. degrees.	Type of transmission.
29th	1315	Beyond Nab D.R. ..	32	314	315*	I.C.W.
	1330	D.R. ..	37	313	315*	C.W.
	1415	D.R. ..	49	313	316*	I.C.W.
	1430	D.R. ..	53	313	313*	C.W.
	1600	D.R. ..	79	312	315*	C.W.
	1615	D.R. ..	83	312	316*	I.C.W.
30th	0720	Fécamp (1) A. ..	93	311	311*	I.C.W.
	0730	,, A. ..	93	311	311*	C.W.
30th	1245	Fécamp (2) A. ..	92	315	315*	I.C.W.
	1300	,, A. ..	92	315	315*	C.W.
31st	1000	D.R. ..	79	313	314*	C.W.
	1015	D.R. ..	75	312	315*	I.C.W.
	1100	D.R. ..	64	309	307*	C.W.
	1115	D.R. ..	60	307	304*	I.C.W.
	1200	D.R. ..	49	302	297†	C.W.
	1215	D.R. ..	45	300	296*	I.C.W.
	1245	D.R. ..	37	295	292*	I.C.W.
	1445	Owers L.V. A. ..	23	297	296*	I.C.W.
	1600	,, A. ..	23	297	297*	C.W.

* Mean of several readings.

† Two readings only.

NOTES.

1. A = at anchor. V.B. = visual bearing. D.R. = dead reckoning.
2. Maximum difference between estimated and observed bearings = 5° in daylight with ship under way and 1° in daylight with ship at anchor.
3. Owing to mist, visibility was very poor on both trips; sea calm throughout.

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(c) Southampton to Jersey

On the part of this route between the Needles and Guernsey, the path of transmission from Fort Monckton to the ship includes about ten miles of the Isle of Wight (see Fig. 4). The outward journey is usually made at night and the return by day, so that a good opportunity is provided of obtaining some information on night effect on the wireless bearings. In some of the tests made during September, 1926, it was noticed that the wireless bearings differed from the estimated bearings by amounts ranging up to 12°, while, at distances exceeding 50 miles, the most obvious signs of night errors were experienced in the form of indistinct and wandering minima of signal intensity. On some occasions successive observations gave bearings differing by as much as 30°, although the mean of a set of observations over a three-minute period gave a much smaller error. On arrival at Guernsey just before sunrise, on one occasion, these effects were still present; twenty minutes later the conditions had very markedly improved, and a steady bearing was obtained only half a degree in error.

Tables 6 and 7 contain summaries of the results obtained on two more recent trips made in September, 1927, and the course of the run on September 16th in Table 6 is plotted in Fig. 4. The direction-finding bearings recorded in these tables will be discussed later in Section 7. Confining attention to the beacon bearings it is seen from Table 6 that the maximum difference between estimated and observed bearings was 4°, and that this difference was encountered twice in the day run and once at night. It appears unlikely, therefore, that any of the differences recorded on this trip can be attributed to night effects. Referring to Table 7 it is seen that with three exceptions the differences between estimated and observed bearings are less than 4°, although night effects were noticed on the outward journey at a range of 69 miles. These three exceptions occurred in successive observations at 1340–1440 on the inward journey in daylight and at ranges of from 34 to 17 miles. In the case of the largest difference of 19° it would appear that some error has crept into the estimation of the ship's position, particularly since in this case, the D.F. bearing is only 6° different from that observed on the rotating beacon. The visual bearings referred to in this and other tables as the means by which the ship's position was obtained consisted in making observations with the ship's magnetic compass of the direction of fixed buoys, light vessels or landmarks in the vicinity. In the rough sea encountered on this voyage, it was naturally difficult to make accurate observations in this manner.

(d) General Conclusions on Observations at Sea

The experience gained on the various sea trips described above appeared to suggest that the bearings observed on the rotating beacon have an accuracy somewhat superior to that of the bearing obtained from an estimate of the ship's position.

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TABLE 6. *Summary of Observations obtained on a Return Voyage between Southampton and Jersey, September 14th to 16th, 1927*

Date, Sept., 1927.	G.M.T.	From information supplied by Captain of ship. Position and how obtained.	From Fort Monckton. Distance. miles.	From Fort Monckton. Bearing. degrees.	Wireless bearings. From Beacon. degrees.	Wireless bearings. By D.F. degrees.	Type of transmission.
14th	2340	Off Egypt Point V.B.	9	90	92	88	I.C.W.
15th	0010	Off Yarmouth Pier V.B.	16	78	74	75	C.W.
	0040	Nr. Needles, .. V.B.†	22	68	65	67	I.C.W.
	0610	At Guernsey .. A.†	110	34	36	33	C.W.
	0710	St. Martin's Pt., D.R.†	111	31	34	33	C.W.
	0740	Nr. Groznez Pt., V.B.†	114	27	30	37	I.C.W.
	1540	At Jersey .. A.	119	21	22*	26*	I.C.W.
	1610	,, ... A.	119	21	22*	24*	C.W.
	1640	,, ... A.	119	21	22*	25*	I.C.W.
16th	0710	Nr. La Corbière V.B.‡	119	25	28	Sigs. too weak	C.W.
	0940	Nr. Casquets.. V.B.‡	96	35	39	36	I.C.W.
	1010	Beyond Casquets V.B.‡	88	39	36	36	C.W.
	1040	49° 54′ N... D.R.‡ 2° 17′ W.	78	40	38	42	I.C.W.
	1110	50° 2′ N... D.R.‡ 2° 9·5′ W.	68	41	38	41	C.W.
	1140	50° 9·5′ N... D.R.‡ 2° 2·5′ W.	55	43	39	41	I.C.W.
	1310	Outside Needles V.B.‡	30	52	48	57	C.W.
	1340	Inside Needles, V.B.‡	20	71	70	71	I.C.W.
	1410	Lepe Middle .. V.B.‡	14	82	82	93	C.W.
	1440	Beacon Buoy.. V.B.	10	119	121	119	I.C.W.

* Mean of several readings. † Sea rough. ‡ Sea smooth.

NOTES.

1. A = moored in dock. V.B. = visual bearing. D.R. = dead reckoning.
2. Maximum difference between estimated and observed bearings on beacon = 4° in daylight. The observed bearings have been corrected for land errors in accordance with the previous calibration of the beacon in the area occupied by the ship.
3. Maximum difference between estimated and D.F. bearings = 11° in daylight. Part of this difference is probably due to land effects for which a correction is not readily applicable.

except when the ship was in calm weather and it was possible to make a fairly accurate fix by visual means. Although signs of night effects in the observed wireless bearings were definitely encountered at distances of 60 miles and upwards, these did not appear to contribute seriously to the differences between observed and estimated bearings. In order to obtain more definite infor-

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TABLE 7. *Summary of Observations obtained on a Return Voyage between Southampton and Jersey, September 20th to 22nd, 1927*

Date, Sept., 1927.	G.M.T.	From information supplied by Captain of ship.			Wireless bearings.		Type of transmission.
		Position and how obtained.	From Fort Monckton.		From Beacon.	By D.F.	
			Distance.	Bearing.			
			miles.	degrees.	degrees.	degrees.	
20th	2340	Nr. Solent Banks V.B.	12·0	81	82	81	I.C.W.
21st	0010	Inside Needles V.B.	21·0	71	71	66	C.W.
	0040	Outside Needles V.B.†	29 0	59	61	61	I.C.W.
	0110	— .. V.B.†	37·0	53	56	53	C.W.
	0140	— .. D.R.†	47·0	47	49	37	I.C.W.
	0210	50° 10·5′ N. .. D.R.† 2° 0·5′ W.	58·0	43	45	46	C.W.
	0240	50° 3′ N. .. D.R.† 2° 8·5′ W.	69·0	41	43§	40§	I.C.W.
	0440	Nr. Casquets.. V.B.†	97·0	37	39	34	I.C.W.
	0510	Nr. Pt. Fougère V.B.†	104·0	35	36	36	C.W.
	0540	At Guernsey .. V.B.†	111·0	34	33	24	I.C.W.
	0610	,, .. A.	111·0	34	34*	44*	C.W.
	0640	Nr. St. Martin's Point .. V.B.‡	113·0	33	34	41	I.C.W.
	1040	At Jersey .. A.	119·0	21	23	Sigs. too weak	I.C.W.
22nd	0710	Nr. La Corbière V.B.‖	119·0	26	23	Sigs. too weak	C.W.
	0940	Nr. Guernsey V.B.‖	103·0	35	35	40	I.C.W.
	1110	49° 58′ N. 2° 12′ W. D.R.†	75·0	39	38	44	C.W.
	1140	50° 8′ N. 2° 4′ W. D.R.†	62·0	42	43	47	I.C.W.
	1210	50° 16′ N. 1° 58′ W. D.R.†	50·0	45	43	59	C.W.
	1240	50° 23′ N. 1° 51′ W. D.R.†	42·0	49	50	47	I.C.W.
	1310	— .. V.B.†	43·0	56	55	65	C.W.
	1340	— .. V.B.†	34·0	76	57	63	I.C.W.
	1410	Outside Needles V.B.†	27·0	65	59	66	C.W.
	1440	Inside Needles V.B.	17·5	76	72	81	I.C.W
	1510	Off Calshot V.B.	7·5	93	90	97	C.W.

* Mean of several readings. † Sea rough. ‡ Sea moderate.
‖ Sea very rough. § Night effect observed.

NOTES.

1. A = moored in dock. V.B. = visual bearing. D.R. = dead reckoning.
2. Maximum difference between estimated and observed bearings on beacon = 19° in daylight. The observed bearings have been corrected for land errors in accordance with the previous calibration of the beacon.
3. Maximum difference between estimated and D.F. bearings = 14° in daylight, at the same time as the error mentioned in 2.
4. The errors recorded in 2 and 3 are exceptionally large for daylight working and are probably due to inaccurate estimation of the ship's position.

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mation upon these night errors it was decided to study the wireless bearings observed from fixed and accurately known positions with the transmission both overland and oversea.

5. Tests carried out at Fixed Points

(*a*) *Description of Tests*

In this series of tests a continuous series of observations was made on the beacon from various positions, each test lasting for a period of twelve hours or more. The places of observation were selected so as to provide a variety of ranges and also to show the difference between transmission over sea and over land. Some of the observations were carried out in the Southern Railway steamers, while the ships were moored at either Havre or Jersey. In these cases the path of transmission was mainly oversea, although, particularly in the case of Jersey, it contained a portion overland. With transmission entirely oversea from the beacon, further observations were carried out on board H.M.S. *Truant* while at anchor at about five miles off the French coast near Fécamp, and also at a position near the Owers Light Vessel. Additional observations with transmission entirely overland were carried out at Southampton Docks, and at Slough and Teddington.

In analysing the observations it was decided to divide the times of observation into day and night periods, the day period lasting from two hours after sunrise until two hours before sunset. This mode of subdividing the 24 hours has been found to be valuable in previous work on wireless direction-finding. Utilising this mode of subdivision, Table 8 (*a*) and (*b*) gives a summary of all the results obtained during the tests under discussion.

(*b*) *Day Observations*

Considering first the day readings, it is seen from Table 8 (*a*) that the error of the mean observed bearing varies with the direction of transmission in the manner already described in Section 3. Also for ranges up to 56 miles the maximum departure of the observed bearings from their respective means is 3°, and that up to the maximum range of 119 miles the greatest deviation from the mean is 6°. Table 8 (*b*) further shows that in all save one case, 100 per cent. of the bearings are within five degrees of the mean, while in most cases over 90 per cent. of the observations agree within two degrees of their respective means. There appears to be no essential difference between the results obtained on C.W. and I.C.W. transmission. The C.W. readings have a slightly superior accuracy, which is probably due to the somewhat greater signal strength obtainable with this type of transmission.

(*c*) *Night Observations*

Turning now to the night readings, it will be seen first of all that, in the case of the tests made at Southampton and Owers,

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TABLE 8 (*a*). *Summary of Observations made at Fixed Points by Day and Night for Transmission over Sea and Land*

DAY.

Position of Observation.	True Bearing.	Distance in Miles.			No. Days Obsvd.	Continuous Waves.					Interrupted Continuous Waves.				
		Total.	Over Sea.	Over Land.		No. Observations.	Mean.	Error.	Variation. Extent of	Variation. Extreme from Mean.	No. Observations.	Mean.	Error.	Variation. Extent of	Variation. Extreme from Mean.
	degrees.						degrees.	degrees.	degrees.	degrees.		degrees.	degrees.	degrees.	degrees.
Havre Quay ..	328·0	105·0	102·0	3·0	4	128	330	+2·0	6·0	±3·0	71	330	+2·0	4·2	−3·0
Jersey Quay ..	21·0	119·0	88·0	31·0	2	66	22	+1·0	6·0	−4·0	45	21	0·0	6·6	+3·6
Southampton Quay	127·5	14·3	—	14·3	2	38	122	−5·5	3·6	−2·0	14	123	−4·5	1·2	+1·2
Off Fécamp—															
Pos. 1	311·5	92·5	92·5	—	1	30	312	+0·5	6·6	+4·2	15	312	+0·5	4·2	+2·4
Pos. 2	315·0	92·0	92·0	—	2	53	316	+1·0	7·8	−6·4	46	316	+1·0	4·8	−2·8
Nr. Owers L.V. ..	297·0	23·0	23·0	—	1	33	295	−2·0	3·6	−2·2	48	294	−3·0	6·0	±3·0
Slough	207·0	55·0	—	55·0	2	49	207	0·0	3·0	−1·8	52	207	0·0	3·0	+1·8
Teddington ..	218·0	56·5	—	56·5	3	92	218	0·0	3·0	−2·0	71	217	−1·0	3·0	+2·0

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TABLE 8 (*a*)—*continued*

NIGHT.

Position of Observation.	True Bearing.	Distance in Miles.			No. Nights Obsvd.	Continuous Waves.					Interrupted Continuous Waves.				
									Variation.					Variation.	
		Total.	Over Sea.	Over Land.		No. Observations.	Mean.	Error.	Extent of.	Extreme from Mean.	No. Observations.	Mean.	Error.	Extent of.	Extreme from Mean.
	degrees.						degrees.	degrees.	degrees.	degrees.		degrees.	degrees.	degrees.	degrees.
Havre Quay ..	328·0	105·0	102·0	3·0	4	350	330	+2·0	27·0	+21·0	168	331	+3·0	21·0	+17·0
Jersey Quay ..	21·0	119·0	88·0	31·0	2	108	23	+2·0	78·0	+55·0	96	23	+2·0	30·0	−17·0
Southampton Quay	127·5	14·3	—	14·3	2	58	123	−4·5	4·8	− 3·0	66	122	−5·5	6·0	+ 4·0
Off Fécamp—															
Pos. 1	311·5	92·5	92·5	—	1	142	312	+0·5	24·0	−15·0	189	312	+0·5	27·6	−18·0
Pos. 2	315·0	92·0	92·0	—	1	151	315	0·0	20·4	−12·0	181	315	0·0	21·0	−12·0
Nr. Owers L.V. ..	297·0	23·0	23·0	—	1	196	293	−4·0	4·8	− 2·6	172	293	−4·0	4·8	+ 2·8
Slough	207·0	55·0	—	55·0	5	180	207	0·0	54·0	+27·0	203	208	+1·0	54·0	+32·0
Teddington ..	218·0	56·5	—	56·5	6	411	216	−2·0	63·6	+32·4	392	216	−2·0	27·0	+15·0

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TABLE 8 (*b*). *Percentages of Differences from Means of Observed Bearings summarised in Table* 8 (*a*)

Position of Observation.	DAY.					
	Continuous Waves.			Interrupted Continuous Waves.		
	No. Bearings Obtained.	Less than 2°. per cent.	Less than 5°. per cent.	No. Bearings Obtained.	Less than 2°. per cent.	Less than 5°. per cent.
Havre Quay	128	96	100	71	94	100
Jersey Quay	66	93	100	45	84	100
Southampton Quay	38	100	100	14	100	100
Off Fécamp (Pos. 1)	30	63	100	15	87	100
,, (Pos. 2)	53	92	98	46	91	100
Nr. Owers L.V...	33	97	100	48	85	100
Slough	49	100	100	52	100	100
Teddington	92	100	100	71	100	100

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TABLE 8 (*b*)—*continued*

Position of Observation.	NIGHT.									
	Continuous Waves.					Interrupted Continuous Waves.				
	No. Brgs. Obtd.	Less than 2° per cent.	Less than 5° per cent.	Less than 10° per cent.	Less than 20° per cent.	No. Brgs. Obtd.	Less than 2° per cent.	Less than 5° per cent.	Less than 10° per cent.	Less than 20° per cent.
Havre Quay	350	87	97	100	100	168	79	98	98	100
Jersey Quay	108	69	84	94	98	96	72	89	98	100
Southampton Quay ..	58	93	100	100	100	66	91	100	100	100
Off Fécamp (Pos. 1)..	142	40	79	97	100	189	47	84	99	100
,, (Pos. 2)..	151	55	84	97	100	181	61	89	98	100
Nr. Owers L.V. ..	196	96	100	100	100	172	93	100	100	100
Slough	180	31	66	86	98	203	49	82	95	99
Teddington	411	53	78	95	99	392	69	92	99	100

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the accuracy of the observations is similar to that obtained in the day time. For in both cases over 90 per cent. of the observations are within 2° of the mean, while the maximum departure in either case is 4°. It may, therefore, be concluded that for a range of 23 miles oversea and 14 miles overland there is no evidence of the existence of any night effects observed on the beacon. Considering next the results obtained at Slough and Teddington by night, it is evident that the night errors have become very serious for a range of overland transmission of about 55 miles. The maximum variation of observed bearing from the mean in either case is seen to be in the neighbourhood of 30°, although Table 8 (*b*) shows that this variation is less than 10° in 86 per cent. or more of the observed cases. Additional observations made by Admiral of the Fleet Sir Henry Jackson at Westminster have also shown the existence of serious night errors of a similar order for transmission at 67 miles overland.

For the case of transmission entirely oversea for a distance of 92 miles, as represented by the observations at Fécamp, the deviations from the mean amount to 12°, although it is to be noted that in from 79 per cent. to 89 per cent. of the cases observed, the deviation was less than 5°. It is thus to be concluded that transmission over a distance of 92 miles entirely oversea gives rise to much less serious night errors than transmission for a distance of 55 miles overland.

The results taken in Havre show slightly greater variations in observed bearings than those obtained at Fécamp, partly owing to the increased range and partly owing to an intervening three miles of land near Havre. In the case of both C.W. and I.C.W. transmissions, however, it is seen that 97 per cent. of the bearings show a variation from the mean of less than 5°.

The greatest range of transmission was obtained with the receiver at Jersey when the distance was 119 miles, of which 31 miles was overland. In this case the greatest deviations were 55° and 17° for C.W. and I.C.W. transmissions, although the proportions of deviations exceeding 5° were only 16 per cent. and 11 per cent. respectively. In this example the errors with C.W. transmissions appear to be somewhat greater than I.C.W. transmissions, but it is not considered that the difference is very material when the possible errors with either system are in excess of 15°. An illustration of the variations experienced at Slough on both C.W. and I.C.W. over a period of several hours by night is given in the lowest graph in Fig. 5.

A feature of night effect which is encountered in direction-finding is a broadening of the signal minima; and a similar occurrence has already been recorded in connexion with the observations on the rotating beacon discussed in the previous Section. In the extreme case this blurring becomes so marked that it is impossible to locate any appreciable change in signal intensity at the receiver as the beacon rotates. Such a phenomenon has been met with once or twice in the tests discussed above, when the distance was over 90 miles oversea. It has been

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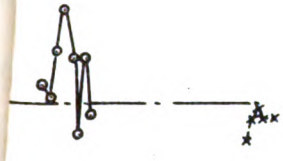
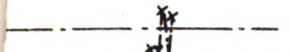
—o— = CW
—·—x = ICW
} λ = 525 METRES.



BEARINGS BY D.F.
(BEACON FIXED.)



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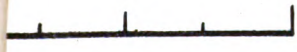

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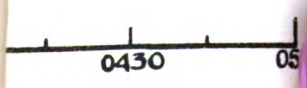

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a much more frequent occurrence, however, in the observations made at Slough and Teddington. In the worst case 12 per cent. of the possible observations were missed owing to the occurrence of this " no minimum " feature on C.W., while the corresponding figure for I.C.W. transmission was 6 per cent. Also during some of the observations made at Slough the received signals passed through four and even six minima during one rotation. The theoretical explanation of this occurrence is discussed elsewhere.[12]

(d) General Conclusions from Observations at Fixed Points

From the results of the tests described above, the following conclusions may be drawn as to the bearings observed on the rotating beacon at fixed receiving positions from which the bearing of the beacon could be accurately located. It is to be assumed that the mean bearings could be corrected in accordance with the calibration curve of the beacon :—

(i) The maximum error in the observed bearing by day at distances up to 56 miles overland or 92 miles oversea is 6° ; generally all the bearings are correct to within 5°, while from 63 per cent. to 100 per cent. are correct to within 2°. At shorter distances up to 23 miles, over 85 per cent. of all observed bearings are correct within 2°.

(ii) When the observations are carried out at night the above accuracies are maintained for distances overland of 14 miles and oversea of 23 miles

(iii) At distances of 92 miles entirely oversea, night errors in bearing having a maximum value of 18° may be encountered, but still it is to be noted that over 84 per cent. of the observed bearings are correct within 5°. At distances exceeding 100 miles oversea the errors become more serious.

(iv) At distances of 55 miles overland the errors are much more serious at night, and may range up to 32°, while only 66 per cent. of them may be correct to within 5°.

(v) It is further to be noted that the mean bearing at any position in Table 8 (*a*) is practically the same for day or night working. This implies that the systematic error of the night variations is very small, so that the effect of the errors mentioned in (iii) and (iv) may be largely compensated for by taking the mean of a number of successive bearings.

(vi) As far as the distances at which night errors are encountered is concerned, there is practically no difference in transmission on continuous and interrupted continuous waves. In some, but not all, cases, the errors with C.W. are somewhat more serious than with I.C.W.

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Owing to the difficulty of anchoring a ship in a fixed position at a considerable distance from land for a period of 12 hours or more, it has not been possible to fill in the gap which occurs in these tests between distances of 23 and 92 miles, all oversea. Reference to the previous Section, however, will show that no evidence of night effect was observed in the cross-channel tests at any distance below 60 miles. It seems reasonable to infer therefore that the reliability of the bearings at 23 miles as recorded in (i) and (ii) above is maintained up to distances of 50 or 60 miles, so long as the path of transmission is entirely oversea. Under these conditions we may expect that about 85 per cent. of all observed bearings will be correct to within 2°, and be subject to a maximum error of 6°. At larger distances night errors begin to be encountered, but do not become serious until the oversea range is in excess of 90 miles.

This conclusion may be compared with the somewhat similar one contained in the following quotation from a paper[10] by one of the present authors, describing experiments made a few years ago to test the reliability of wireless direction-finding oversea:

"When, however, the transmission is entirely oversea, so as to be well clear of any land defects, the accuracy of observed bearings is maintained within the limit of 2° for night as well as for day working at distances approaching 60 miles; and even up to 100 miles over 90 per cent. of the bearings are correct within 2°, the limiting error under ordinary working conditions being 4°."

Such accuracies refer to the bearings obtained at a *land* D.F. station; and are superior to those obtainable with a ship D.F. installation, a matter which is discussed in Section 7 below.

The similarity between the effects encountered in bearings observed on a rotating beacon and on a direction-finder is discussed in another paper,[13] and the marked agreement between theory and experiment in the two cases is worthy of notice as indicating the validity of the explanation of night phenomena in wireless communication.

6. Range of the Beacon for Reliable Working

As at present installed the Fort Monckton Beacon employs a 6-turn frame coil 5 feet square, and normally operates with a current of 40 amperes at a wave-length of 525 metres. In its own plane such a loop has an effective radiation of nearly 7 metre-amperes expressed in the terms normally applied to an open aerial transmitter. For comparison purposes it may be stated that the effective radiation of the fixed beacon stations, now being installed for the use of ship D.F. sets, is about 35 metre-amperes on interrupted continuous waves.[11]

With the rotating beacon transmitter operating under the above conditions, and using continuous waves, the working range appears to be very good. For example, using the Marconi type

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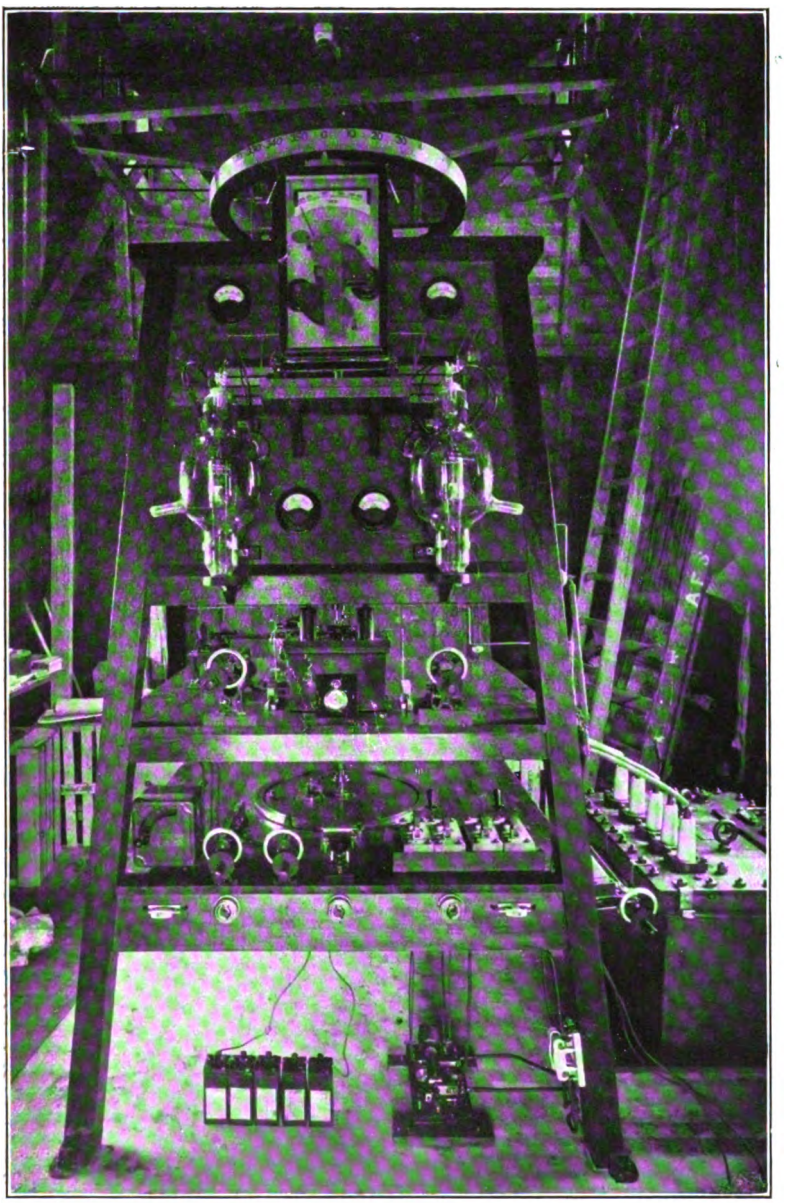

FIG. 6.—*Control Panel and Rectifying Valves, Fort Monckton Rotating Beacon.*

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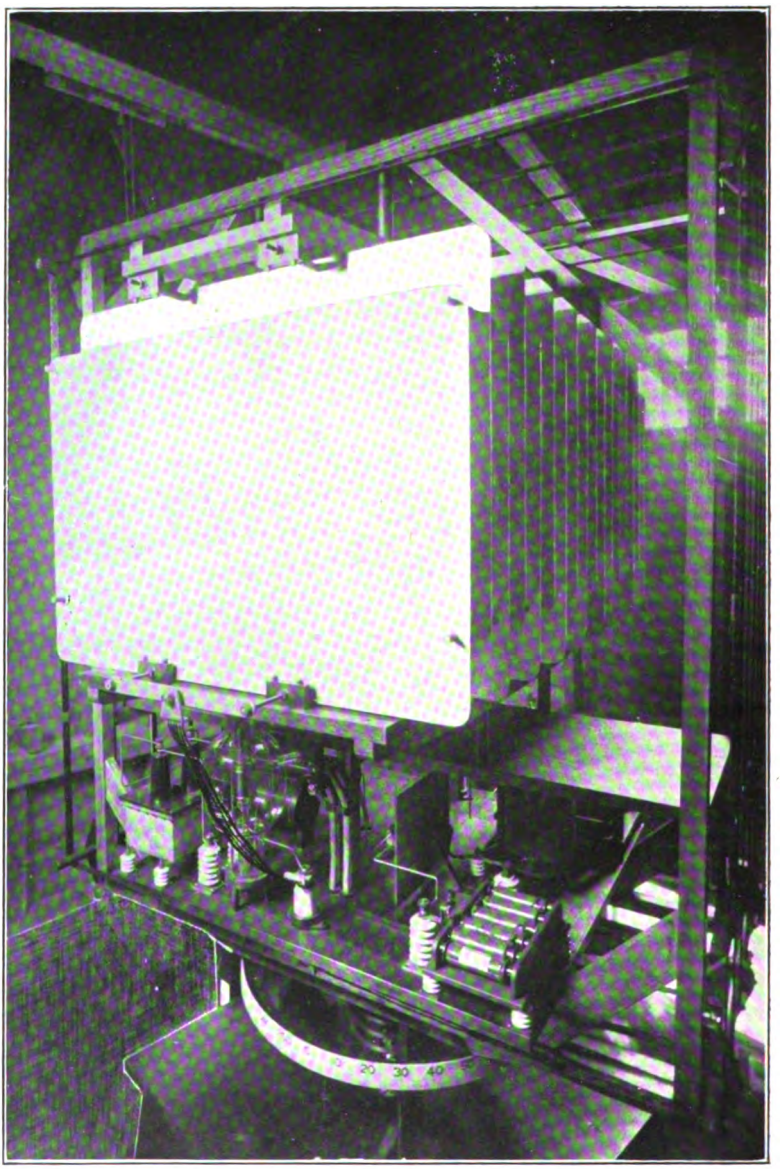

FIG. 7.—*View of Transmitter—Frame Coil, Condenser, Valve, etc., Fort Monckton Rotating Beacon.*

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R.M. 4B receiver (1 detector valve with retroaction and 1 low-frequency amplifying stage) installed in the Southern Railway boats, adequate signal strength is obtained for accurate bearings at a range exceeding 100 miles oversea under good conditions. In the presence of interference from atmospherics or from spark or broadcasting stations, the accuracy of the observed bearings is seriously impaired at such distances. On some occasions it has been found that, when other conditions were favourable, very serious interference was caused by stray induction fields which were traced as originating from the electric fan motors on board the ship.

Similar results were obtained with a portable three-valve receiver (one retroactive detector and two low-frequency amplifying stages), which has been largely used in these tests. Although such a set gives a slight advantage over the two-valve receiver when used in a fixed position under quiet conditions, little if any advantage is gained on board ship owing to the limitation set by the general noise and vibration when the ship is in motion.

With interrupted continuous-wave transmission and a crystal receiver (Marconi type 31A) on the same ships, the useful range for bearing observations is about 7 miles, when the signal minima are silent for about 5 seconds. At a range of 14 miles bearings can be taken under favourable conditions, but they are of doubtful accuracy since the silent minima last for about 10 seconds (i.e. 60°).

Tests carried out with the valve receivers mentioned above, and used on interrupted continuous-wave transmissions with the receiver not oscillating, showed that under very good conditions a range approaching 100 miles is obtainable. But with the general noise and interference accompanying reception on a ship at sea this range is immediately reduced to twenty miles or less. Most valve receivers, however, would be capable of self-oscillation, and the I.C.W. transmissions could be received on the heterodyne beat method, when the results obtained would be comparable with those mentioned above for C.W. transmissions.

For overland working the range of adequate signal strength is considerably reduced, and it is found that even at sixty miles from the beacon good accuracy of observed bearings is dependent upon a somewhat infrequent absence of interference from other transmissions.

In considering the above ranges it should be pointed out that the method of producing I.C.W. at the Fort Monckton transmitter is not the most efficient, since it consists in merely disconnecting the smoothing circuit from the rectified alternating current used for the high-tension supply to the anode of the transmitting valve. With a more suitable method of interrupting the continuous oscillations, it is possible that a greater range might be obtained when using a crystal or non-oscillating valve receiver.

Combining the experience recorded above with the detailed results on night errors discussed in the previous section, it may be stated that the reliable working range of the type of beacon

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which has been installed at Fort Monckton, is of the order of fifty miles for both day and night working, when the path of transmission is entirely oversea and clear of any land or coastal boundaries. Within this range the majority of the wireless bearings are accurate to within two degrees, but their reliability is dependent to some extent upon the observer, and also upon the type of chronograph employed. At ranges beyond fifty miles, bearings of a lower order of accuracy may still be taken as conditions permit, and the reliability of these observed bearings may generally be improved by taking the average of a number of successive readings. At ranges of 100 miles and over, bearings taken on the rotating beacon in daylight are still reliable, but at night they are subject to errors of a rather serious order in the same manner as those encountered in wireless direction-finding. Also as an analogous case to that of direction-finding, rotating beacon bearings are subject to errors by day and night when the path of transmission is overland or along a coastal boundary, and the variable night errors are encountered at a smaller range when the transmission is wholly or partly overland.

Finally, it may be said that, other things being equal, no essential difference in results has been observed between the use of continuous waves and interrupted continuous waves.

7. Comparison of Bearing Observations by Beacon and by Direction-Finder

With a view to obtaining experience on the relative merits of the Rotating Beacon and the Direction-Finder as a means of obtaining wireless bearings, a direct comparison of the two systems has been carried out under a variety of conditions.

(*a*) *Day Tests at Various Positions*

In the first place tests have been made with two sets of portable apparatus at different positions on land. At each site a simple receiver with a vertical aerial was employed for the reception of the signals from the rotating beacon. Adjacent to this, but at a sufficient distance to avoid mutual interference, a single-frame coil direction-finder was set up for the purpose of taking ordinary D.F. bearings while the beacon loop was fixed with its plane approximately in the direction of the receiver. As a further precaution against producing a spurious reading on the D.F. set, the vertical aerial was disconnected during the taking of bearings by D.F. As far as was practicable a favourable site was chosen on each occasion, so as to reduce the possibility of local errors occurring on the direction-finder. The accuracy of setting the direction-finder by the aid of a prismatic landing compass is considered to be within 0·5°.

A summary of the results obtained in these experiments is given in Table 9. From these it is seen that the error of the mean bearing observed on the direction-finder is generally different

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TABLE 9. *Comparison of Bearings taken by Rotating Beacon and by Direction-Finder at various Positions*

(Continuous-Wave Transmission, $\lambda = 525$ metres)

Position.	Fort Monckton.		By Rotating Beacon.			By D.-F.			Remarks.
	True Bearing.	Distance.	No. Observations.	Error of Mean Bearing.	Extent of Variation.	No. of Observations.	Error of Mean Bearing.	Extent of Variation.	
	degrees.	miles.		degrees.	degrees.		degrees.	degrees.	
St. Catherine's Pt. ..	27·5	15·5	14	+1·0	7·2	12	−1·5	0·2	On Isle of Wight.
Brighstone Down ..	53·0	13·9	12	+1·0	1·6	10	+3·5	0·7	,, ,,
Wootton	57·0	5·1	6	−3·0	1·8	12	+1·5	1·5	,, ,,
Bouldnor Cliff ..	73·5	14·3	12	−1·0	2·0	12	−3·0	0·2	,, ,,
Lulworth	79·5	48·9	20	+2·5	4·5	14	−0·5	0·1	
Tanner's Lane ..	84·8	15·4	12	0·0	1·2	8	+2·5	0·5	
Stone Point	94·0	9·4	4	−3·5	0·7	8	+1·0	0·5	
Beaulieu Rails ..	95·0	15·0	12	−5·0	1·7	8	+1·5	0·7	
Picket Post	102·0	26·5	14	−8·0	4·8	12	−2·0	0·6	
Dibden Common ..	113·5	14·8	16	−1·0	3·8	8	+7·0	0·6	
Romsey	136·0	21·6	12	+2·0	2·4	12	−0·5	0·5	
Slough	207·0	55·0	49	0·0	3·0	36	+1·0	1·5	
Bembridge	337·0	6·5	18	0·0	2·9	10	+3·5	0·7	On Isle of Wight.
Seaview	350·5	3·7	8	+1·0	3·0	14	−1·0	2·0	,, ,,

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from the error of the bearing observed on the rotating beacon for each position, but the range of errors on the two systems is about the same order. These errors are undoubtedly due to deviation of the waves at the boundaries between land and sea, and it is to be noted that the D.F. errors are in general of the correct sign and magnitude to be in accord with previous experience on the effect of coastal refraction in radio direction-finding. In some cases, e.g., Romsey and Slough, it was noticed that part of the error was due to local conditions and that a change of the direction-finder by some 20 to 100 yards produced a change in bearing of 1° or 2°. No such effects were observed on the results taken on the rotating beacon, the recorded bearing being practically immune from the effect of conditions local to the receiver. It is thought that the above results indicate the possibility of the reflection, as well as of the refraction, of waves at a coastal boundary, and that the rotating beacon provides a useful means of investigating this phenomenon, since it can be used as a "null" method for transmission in the desired direction.

(*b*) *Day and Night Errors compared*

The next tests were carried out with the object of studying the variations in bearings observed with the two systems over periods of from one hour upwards. Two sites were selected for these; the first was at Slough, where a single-frame-coil direction-finder was used in conjunction with another receiver working on a vertical aerial; the second was at St. Helier's Quay, Jersey, where observations were made in one of the Southern Railway's steamships fitted with the Marconi-Bellini-Tosi direction-finder and the ordinary aerial respectively as fitted on that ship. A summary of the results is given in the following Table 10.

The day readings summarised in 10 (*a*) indicate that the observed bearings have about the same accuracy for the two systems, and also that similar results are obtained with continuous-wave transmission as with interrupted continuous waves. The slightly greater variations obtained on the direction-finder and with I.C.W. transmission are probably due to the somewhat reduced signal strength obtainable in these cases.

At night time it is seen that the variations in observed bearings are quite serious in all cases. The extent of the variation ranges from 20° to 57° in the case of the rotating beacon bearings, and from 69° to 130° in the case of the D.F. bearings. Table 10 (*c*) shows that even under these conditions over 86 per cent. of the bearings taken on the rotating beacon are in error by less than 10°, while in the case of the D.F. bearings over 62 per cent. are in error by less than 10°. From the same table it appears that the errors are sometimes, but not always, more serious on C.W. than on I.C.W. transmissions, but the difference is not consistently marked. Night variations in D.F. bearings have been studied at considerable length, and reference may be made to a recent publication[12] for further discussion of this subject. It is now

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TABLE 10 (*a*). *Comparison of Day and Night Errors observed on the Rotating Beacon and on a Direction-Finder from Fixed Position.* ($\lambda = 525$ *metres.*)

Continuous Waves.

Position of Observation.	From Fort Monckton.				No. of Days Observed	By Rotation.				By D.-F.				No. of Nights Observed	By Rotation.				By D.-F.			
	True Bearing.	Distance in Miles.				No. Observations.	Error of Mean Bearing.	Variation.		No. Observations.	Error of Mean Bearing.	Variation.			No. Observations.	Error of Mean Bearing.	Variation.		No. Observations.	Error of Mean Bearing.	Variation.	
		Total.	Over Sea.	Over Land.				Extent of.	Extreme from Mean.			Extent of.	Extreme from Mean.				Extent of.	Extreme from Mean.			Extent of.	Extreme from Mean.
	degrees.						degrees.	degrees.	degrees.		degrees.	degrees.	degrees.			degrees.	degrees.	degrees.		degrees.	degrees.	degrees.
Slough ..	207·0	55·0	—	55·0	2	49	0·0	3·0	−1·8	36	+1·0	1·5	+0·9	5	180	0·0	54·0	+27·4	194	+2·0	130·0	+70·6
Jersey Quay	21·0	119·0	88	31·0	2	31	+3·0	3·6	±1·8	6*	+3·0	6·0	−3·3	2	43	+1·0	57·0	+43·8	44	+4·0	72·5	−37·0
Interrupted Continuous Waves.																						
Slough ..	207·0	55·0	—	55·0	2	52	0·0	3·0	+1·6	66	+1·0	1·5	+0·9	5	203	+1·0	54·0	+32·1	199	+1·0	85·0	+57·1
Jersey Quay	21·0	119·0	88	31·0	2	33	+2·0	5·4	+3·0	14*	+4·0	6·5	−3·5	2	43	+1·0	20·4	−10·5	50	−4·0	69·0	−44·5

TABLE 10 (*b*). *Percentage of "No Minimums" and Differences from Means in Night Runs in* 10 (*a*)

Position of Observation.	Continuous Waves.												Interrupted Continuous Waves.											
	By Rotation.						By D.-F.						By Rotation.						By D.-F.					
	No. Bearings Obsd.	Less than				No. Mins.	No. Bearings Obsd.	Less than				No. Mins.	No. Bearings Obsd.	Less than				No. Mins.	No. Bearings Obsd.	Less than				No. Mins.
		2·0°	5·0°	10·0°	20·0°			2·0°	5·0°	10·0°	20·0°			2·0°	5·0°	10·0°	20·0°			2·0°	5·0°	10·0°	20·0°	
		%	%	%	%	%		%	%	%	%	%		%	%	%	%	%		%	%	%	%	%
Slough	180	31	66	86	98	12·2	194	21	43	62	80	8·5	203	49	82	95	99	6·0	199	42	64	80	93	10·8
Jersey Quay	43	35	65	86	95	12·2	44	20	32	64	82	12·0	43	43	63	95	100	15·7	50	16	40	72	88	3·9

* One day only.

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well known that these errors are due to the reception of waves from the transmitter deflected in the upper atmosphere, and it is realised that in the results quoted above the variations on the direction-finder are exaggerated by the fact that the loop transmitter radiates very much more to the upper atmosphere than is the case with a vertical aerial. A graph showing the manner of typical variations taking place on the two systems is shown in Fig. 5, which is plotted from the results obtained during one of the nights of observation at Slough.

The main conclusion to be drawn from the results discussed in this section is that, under the same conditions, both systems of obtaining wireless bearings are subject to night errors of the same serious order. It is to be noted, however, from Table 10 that the mean bearing at night agrees within one degree with the day mean, so that one method of mitigating the effect of night variations is to take the mean of a number of successive bearings. A theoretical discussion of the possible methods of eliminating these errors is given in a separate publication.[13]

(*c*) *Comparison Tests at Sea*

Some of the test runs made in ships between Southampton and Jersey, discussed in Section 4 (*c*) above, were carried out in a ship which is fitted with a direction-finder using fixed frame coils on the Bellini-Tosi system. The opportunity was therefore provided of comparing the two systems of obtaining wireless bearings under actual sea-going conditions. The results obtained on two trips, in which observations were made successively on the rotating beacon and on the direction-finder with the beacon fixed in the maximum signal position, are given in Tables 6 and 7, to which reference was made in Section 4.

Considering first the results in Table 6, it is seen that with two exceptions the D.F. bearings agree with the estimated bearings to within 5°. Of the two exceptions, one shows an error of 10° at a range of 114 miles, while the second shows an error of 11° at 14 miles distance, when the ship was proceeding up the Solent. It is thought that a portion of these errors, but probably not more than 3° or 4°, is due to a land deviation effect which is difficult to compensate for on a ship D.F. set. During the same run, the rotating beacon bearings, after correction for the 1° or 2° of error in some positions from the calibration curve Fig. 3, shows a maximum departure from the estimated bearing of 4°.

In searching for an explanation of the larger D.F. errors above, it is to be remembered that the D.F. bearing is observed relative to the ship's head and that, therefore, the accuracy of the bearing is limited to the accuracy with which the ship's compass indicates the *instantaneous* direction of the ship's head. In the ship in which the experiments were carried out, the D.F. set is operated from the wireless room, and on a signal being given to the bridge the compass reading is taken by one of the ship's officers. In anything but a very calm sea it is naturally difficult

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to keep the ship's head steady to within one or two degrees, and in a rough sea the swing may amount to five degrees or more. Also there is probably a lag between the actual direction of the ship's head and the reading of the compass. Finally, unless it is calibrated at frequent intervals, it is doubtful if the reading of a magnetic compass is accurate to within 2° or 3° over all parts of the scale. These considerations may result in the accuracy of a ship direction-finder installation being appreciably inferior to that of a similar apparatus on land. The errors due to the above cause will probably decrease with an increase in the size of the ship, but the ship mentioned above is probably typical in size to many which will, in the future, utilise wireless bearings for navigation. It is also to be remarked that the ship D.F. set is subject to a quadrantal error, for which correction or compensation is necessary.

On the other hand, the rotating beacon method of obtaining wireless bearings is free from all these objections. Except for the interfering effects of noise and general vibration, the accuracy of the observed bearings is the same whether the ship is in dock or at sea.

The above conclusions are considered to be largely confirmed by the results of a second trip recorded in Table 7. In this case a rough passage was encountered in both directions, and, due to the erratic motion of the ship, many of the D.F. bearings suffered in accuracy. Errors up to 10° were recorded on the outward journey; one of these occurred while the ship was moored at Guernsey, and is possibly due either to night effect or to a local error while in the harbour. The return trip was made in daylight, and while on the open sea an error of 14° occurred at 1210 G.M.T. In the position indicated at 1340 G.M.T. it is seen that the bearings by the rotating beacon and by the D.F. set differ by 19° and 13° respectively from the bearings obtained from the ship's position at a range from Fort Monckton of only 34 miles. Since the weather was very bad on this occasion, it seems reasonable to conclude that the estimated bearing is some 12° or 15° in error, and that both the wireless bearings are superior in accuracy to that obtained by other navigational methods. The agreement shown in the remaining cases between the bearings by the rotating beacon and those obtained from the ship's estimated positions appears to show that the latter are, on the whole, fairly accurate.

(*d*) *Reception of Beacon Transmissions on Loop and Aerial*

Since it may sometimes be required to receive and observe signals from a rotating beacon on a closed loop or D.F. set instead of on an open aerial, it was considered to be useful to make a brief comparison between the two cases. When working in daylight or under such conditions at night as to be free from night variations, it has been found that the bearings observed on a loop agree with a maximum departure of one degree with

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those observed on an aerial. When operating under conditions of night variations, however, the errors encountered on the loop receiver are greater than those observed on the aerial. This effect, which is illustrated in Fig. 5, is due to the fact that with downcoming waves arriving at the earth's surface the resultant horizontal magnetic field (operating on the loop) is of greater intensity than the vertical electric field (operating on the vertical aerial). These results have been confirmed for both continuous-wave and interrupted continuous-wave transmission. It is to be concluded from this experience that it is inadvisable to use a loop receiver when an aerial is available for reception from a rotating beacon.

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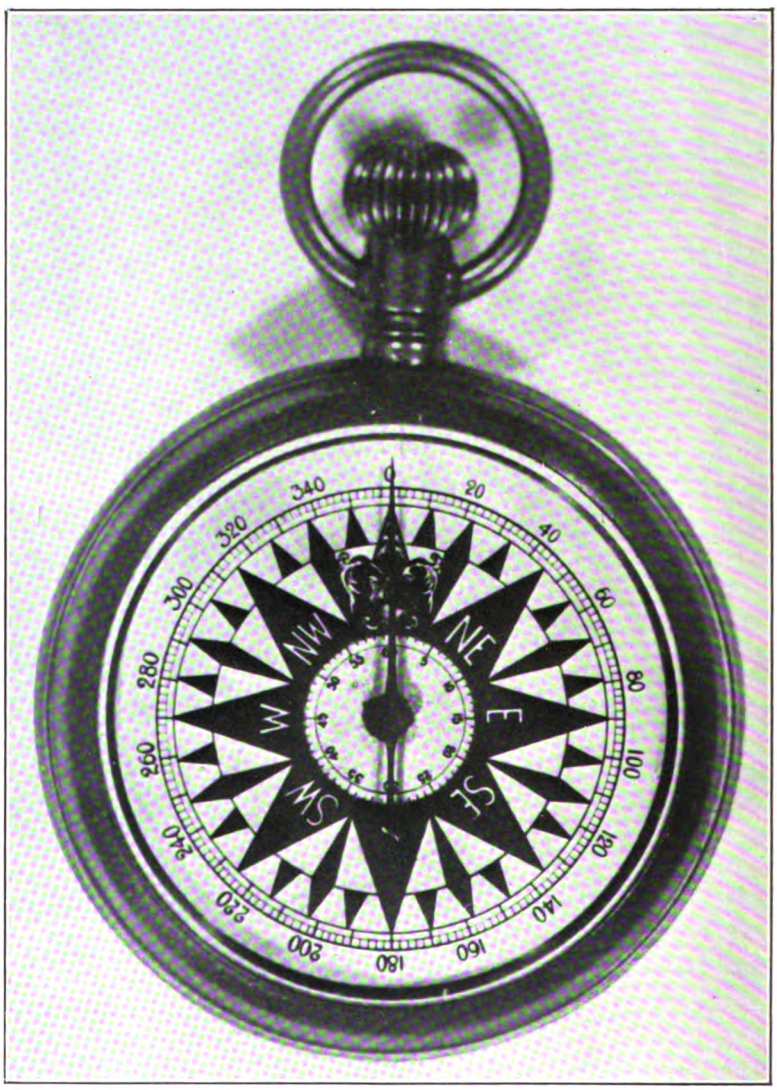

FIG. 9.—*Stop-Watch fitted with Compass Dial from which the Geographical Bearing of a Rotating Beacon is read off directly.*

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APPENDIX 1

NOTE ON A SPECIAL DIAL FOR TIMEPIECES TO BE USED WITH ROTATING WIRELESS BEACONS

To avoid the necessity of making the calculations necessary when using an ordinary chronograph in connexion with a rotating beacon, it is more convenient to provide the watch or timepiece with a special dial from which the bearing may be read off directly. A stop-watch may be used provided with a dial somewhat similar in type to that proposed for use with the Telefunken Compass in 1912 (*Electrician*, 1912, **69**, 270). In this case the observations were made on the points of maximum signal strength, and the device did not come into widespread use owing probably to its limited accuracy and to the lack of uniformity of the time of rotation of the transmitter. As described in Section 2 (*b*) of the report a modern rotating wireless beacon can, however, be accurately controlled by a vibrating tuning-fork, and its rotation is thus very uniform and can be set to make one revolution per minute to within a limit of about one-hundredth of a second.

A dial is shown in Fig. 8 as being suitable for mounting on a watch whose index hand rotates once in sixty seconds, and for use with a rotating beacon making one revolution per minute. The outer scale is calibrated directly in degrees from 0° to 360°, the second scale is marked in points of the compass, while the innermost scale is marked off in seconds. It is evident that if the index hand of a timepiece provided with such a dial is started from the 0° or N. point when the beacon gives its characteristic N. signal, then when the received signal passes through its minimum intensity the position of the index hand will indicate directly the bearing of the transmitter from the receiver. If necessary the scales of the dial could be arranged so that either true or magnetic bearings can be read off as desired. In this case an adjustment would be necessary between the two scales, to allow for the magnetic scale to be set according to the magnetic variation at the place of observation. The photograph, Fig. 9, shows an ordinary sixty-seconds stop watch provided with a dial similar to Fig. 8.

In cases where the receiver is situated directly North or South of the transmitter, the characteristic North signal would possibly not be heard owing to the passage of the signal intensity through its minimum. To allow for such conditions it is usual to arrange for the transmitter to send another characteristic signal corresponding to the East position. If a timepiece with a dial as in Fig. 8 is employed in such a case the same procedure may be followed, except that 90° must be added to the dial reading to obtain the correct bearing. On the other hand, a separate watch might of course be used, the dial of which is suitably engraved to permit of starting from the E. point, as shown in Fig. 10. Alternatively the watch may be provided with the means for rotating the dial until the starting position of the index hand lies over the 90° or E. point of the bearing scales.

Variations on the dial may be made to permit of its use with a beacon rotating at any other speed than once a minute. For example, for certain purposes it would be more convenient to employ a beacon which made one revolution in two minutes. In this case a dial of the type shown in Fig. 11 may be employed on a timepiece whose index hand rotates once a minute.

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Considering that the important application of rotating wireless beacons is for navigation purposes, it is much more convenient to have the index dial marked out as a compass scale, with which the navigator is familiar, rather than as a time scale, since the time factor is but an intermediary step in the obtaining of a wireless bearing in this manner. The application of the dial is not, of course, restricted to wireless beacons. It can equally well be applied, for example, to a sound signalling scheme, in which the direction is obtained from a time measurement of some rotating component.

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FIG. 8.—*Working from N Signal on Beacon making one revolution per minute.*

FIG. 10.—*Working from E Signal on Beacon making one revolution per minute.*

FIG. 11.—*Working from N Signal on Beacon making one-half revolution per minute.*

Compass Dials suitable for Watches used with Rotating Beacons.

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APPENDIX 2

The Effect of a Tuned Aerial on the Radiation from a Rotating Beacon

1. Theoretical Analysis

The radiation from a vertical loop of the type employed in a rotating beacon transmitter is given by an expression of the following form :—

$$H_1 = \frac{K_1 \cos A}{d_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where H_1 is the strength of the magnetic field at a point distance d_1 from the loop and the direction of which makes an angle A with the plane of the loop. K_1 is a constant depending upon the dimensions of the loop and the wave-length employed.

If a tuned aerial is placed in this radiation field the current induced in the aerial will be

$$I = \frac{H_1 c}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where c = velocity of electromagnetic waves
and r = resistance of aerial circuit.

The re-radiated field from this aerial will be

$$H_2 = \frac{K_2 I}{d_2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

being constant in all directions.

Now consider the radiation at a point R (Fig. 12 (*a*)) distant d_2 and d_3 from an aerial T and a loop L respectively, the direction of R from the loop making an angle C with the line joining loop and aerial.

The fields H_L and H_T due to the loop and aerial respectively will be given by the expressions

$$H_L = \frac{K_1 \cos (A + C)}{d_3},$$

$$H_T = \frac{K_2 I_T}{d_2},$$

$$= \frac{K_2 H_1 c}{d_2 r},$$

$$= \frac{K_2 K_1 c \cos A}{d_1 d_2 r}.$$

Thus the total field at R will become zero when

$$H_L + H_T = 0,$$

i.e., when $$\frac{\cos (A + C)}{d_3} + \frac{K_2 c \cos A}{d_1 d_2 r} = 0. \quad \ldots\ldots\ldots\ldots \quad (4)$$

Since with the rotating beacon, a bearing is obtained by observing the instant at which the received signal intensity passes through zero, it is evident that equation (4) will give the position of the loop at this instant. For the bearing to be correct the angle (A + C) should be equal

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to 90°, i.e., the plane of the loop should be perpendicular to LR. Any error in bearing due to the presence of the aerial at T is thus given by the departure of (A + C) from 90° when the field at R is zero. Hence if D is the error in bearing then

$$D = 90 - (A + C)$$

and equation (4) may be written in the form

$$\sin D = \frac{-K_2 c}{r} \cdot \frac{d_3}{d_1 d_2} \sin (D - C),$$

whence

$$\tan D = \frac{K_3 \frac{d_3}{d_1 d_2}}{1 + K_3 \frac{d_3}{d_1 d_2}} \sin C \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

in which $K_3 \left(= \frac{K_2 c}{r}\right)$ is a constant depending upon the receiving aerial and the wave-length only.

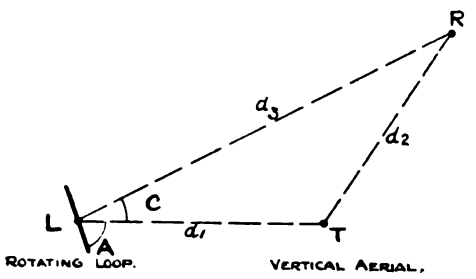

FIG. 12 (*a*).

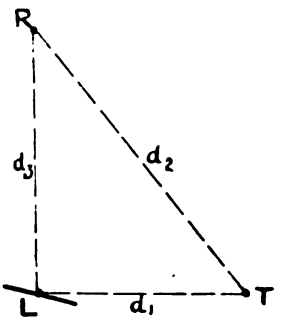

FIG. 12 (*b*).

Diagrams illustrating Relative Positions of a Rotating Beacon L, a Tuned Aerial T, and a Distant Receiver R.

The order of the possible values of the error in bearing D can be obtained by considering the following cases :—

(*a*) *Tuned aerial distant from transmitter and receiver*

If d_3 is small compared with both d_1 and d_2, then the error D will be small, i.e., the accuracy of bearings observed on a rotating beacon is unaffected by the existence of aerials tuned to the beacon wave-length but situated at a distance large compared with that separating the beacon and receiver.

(*b*) *Tuned aerial near transmitter*

If the aerial is close to the transmitter then d_3 and d_2 will be sensibly equal and will be large compared with d_1. Hence equation (5) will reduce to the form :—

$$\tan D = \frac{K_3}{d_1} \sin C \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

The resulting error will thus vary according to the direction of the aerial from the beacon. The aerial will produce its maximum error given by

$$\tan D = \frac{K_3}{d_1},$$

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when its direction from the beacon is perpendicular to that of the receiver. (See Fig. 12 (*b*).) When, however, the aerial is on the line joining the beacon loop and the receiver, the error produced will be zero, since the angle C is zero. It is to be noted that if d_1 is very small compared with the wave-length the induction field from the beacon will be greater than the radiation field, and equation (6) would take the form

$$\tan D = \frac{K_4' \sin C}{d_1^2}.$$

(*c*) *Tuned aerial near receiver*

In this case d_3 and d_1 will be practically equal and will be large compared with d_2; so that equation (5) will reduce to the form

$$\tan D = \frac{K_3}{d_2} \sin C \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

which is similar to (6) above.

It would thus appear that a tuned aerial placed at a given distance from the receiver should produce the same error in bearing as that resulting from the same tuned aerial placed at the same distance from the rotating loop transmitter. When, however, the aerial is near the receiver the angle C subtended at the transmitter must be small, and therefore equation (7) will become

$$\tan D = \frac{K_3}{d_2} . C \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

from which it is seen that the tangent of the error is directly proportional to the angle C.

2. Experimental Test of Error on a Rotating Beacon due to a Neighbouring Aerial

In May, 1927, an experiment was carried out at the Fort Monckton beacon in order to ascertain the effect of a tuned aerial placed near the transmitter on the bearing observed at a distant receiver. A single-wire aerial, 150 feet long, was erected near the beacon on a mast about 60 feet high, the shortest distance between this aerial and the beacon coil being 36 feet. With the beacon operating at its normal power and wave-length, the current induced in this aerial varied, of course, with the orientation of the beacon coil, and attained a maximum value of 18 milliamperes with the aerial tuned.

Employing three receiving stations, distant respectively 4·5, 5·0 and 57·0 miles from the beacon in different directions, a systematic series of tests was carried out in which the above aerial was in turn connected direct to earth, left insulated, and then tuned with a normal circuit connexion to earth and also distuned to varying degrees. In no case, however, was any error in bearing exceeding 1° observed at any of the three receiving stations throughout the whole of these tests.

It may thus be concluded that an aerial of the type described above, erected at a distance exceeding 40 feet from the transmitter, will produce a negligible effect on the bearings observed at a distant receiver.

3. Conclusion

It has been shown in the preceding sections that a tuned aerial does not affect bearings observed on a rotating beacon transmitter unless the distance of the observing station is large compared with the distance of the aerial from *either* transmitter or receiver. Also the observed bearings are unaffected by a tuned aerial placed on the line joining transmitter and receiver.

Furthermore, it has been shown experimentally that a tuned aerial with an effective height of about 30 feet, placed at a distance of about

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40 feet from the transmitter only produces an error in bearing of about one degree at a receiver at a distance of, say, more than one mile.

This last conclusion does not preclude the necessity of avoiding overhead wires and large masses of metalwork over a considerable area in the proximity of a beacon transmitter, since the cumulative effect of such disturbances may be more serious than that of an isolated aerial.

At the receiving end, however, the conditions are somewhat different; for unless the disturbing conductors subtend with the receiving aerial an appreciable angle at the transmitter, the error produced will be small. This deduction accounts for the fact which is illustrated by the experimental results given in Section 2 (*d*) of this report, that the accuracy of observed bearings is largely independent of the presence of tuned aerials or wires and metalwork in the neighbourhood of the receiver.

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APPENDIX 3

Results of some Further Experiments on the Screening of a Rotating Beacon Transmitter

Introductory

In Section 2 (*d*) of the present report a brief description is given of the attempts made to improve the quality of the signal minima by surrounding the whole of the rotating portion of the beacon by an open-wire screen. This screen should have the effect of neutralising any antenna effect present in the radiation from the coil transmitter, and when it was first set up it was observed that at some receiving points the quality of the two signal minima was equalised. This screen remained in position throughout the whole of the experiments carried out at sea and on land during the period March to September, 1927. Since the termination of these experiments, as described in the main body of the report, a series of observations has been carried out to study the effect of the screen in more detail.

Procedure of Tests

The procedure adopted in these tests was to make bearing observations on the beacon at approximately fortnightly intervals at eight fixed receiving points, within a radius of five miles from the beacon. Four of these points were situated on the landward side of the beacon and the remaining four were at sea on Forts and a Light Vessel. Concurrently, observations were made daily as far as possible, from two fixed stations at Ditton Park (Slough) and Teddington throughout the tests. During the first six weeks of these tests the beacon was fully screened in the manner already described. During the remainder of the tests, the open-wire screen surrounding the rotating loop was removed, leaving only the wire-netting screen round the lower portion of the transmitting hut. By summarising the results taken in these tests, it should be possible to ascertain the effect of the screen independently of any daily variations which may be present.

Summary of Results Obtained

A summary of all the results obtained in these tests is given in the following table. This summary shows the mean bearings, with the corresponding errors and variations, and also the width of minima, for all the observations carried out at the various sites.

Discussion of Results

A first survey of these results shows that it is difficult to draw any very definite conclusions as to the effect produced by the presence of the screen. In the case of the observations taken at sea, the effect of removing the screen was to increase the bearing by amounts varying from 0·6° to 2·3°. (See Column 5.) With the exception of the readings taken at Hill Head, however, no effect was produced on the bearings observed at the positions on land. In the case of Hill Head the transmission takes place along the coast, and some peculiar effects are therefore to be expected. For example, the observations may be subjected to some effect due to

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TABLE.—*Summary of Observations on Fort Monckton (5AY) during Test on Open-Wire Screen. September to December, 1927*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Position of Observation.	Condition of Screen.	No. of Observations.	Bearings.			Variation.		½ Width of Signal Minimum.	
			Mean.	Error of Mean.	Direct Minus Reciprocal.	Extent of.	Extreme from Mean.	Mean of 1st Min.	Mean of 2nd Min.
			degrees.	degrees.	degrees.	degrees.	degrees.	degrees.	degrees.
Observations at Sea—									
Warner L.V.	Up	46	318·6	+1·0	−1·6	3·6	−1·8	0·1	0·2
,, ,, ...	Down	44	319·2	+1·6	−0·7	3·6	−2·4	0·4	0·4
Nomans Land Fort ..	Up	30	325·2	0·0	−1·4	3·0	+1·8	0·2	0·2
,, ,, ,, ..	Down	48	325·8	+0·6	+0·2	6·0	±3·0	0·2	0·5
Horse Sand Fort	Up	44	303·0	0·0	−2·9	4·2	+2·4	0·1	0·2
,, ,, ,, ...	Down	44	305·3	+2·3	−0·6	2·4	−1·7	0·3	0·4
Spit Bank Fort	Up	30	281·4	−1·6	−2·1	4·2	+2·4	0·2	0·2
,, ,, ,, ...	Down	40	282·9	−0·1	−0·4	4·8	+2·7	0·3	0·4
Observations on Land within 5 miles—									
Fort Cumberland	Up	54	253·3	−0·2	−2·1	10·2	+5·3	0·3	0·2
,, ,, ...	Down	48	253·3	−0·2	−0·1	5·4	+2·9	0·7	0·2
Near Portchester	Up	38	181·6	+3·6	−1·4	4·2	+2·6	0·3	0·2
,, ,, ...	Down	32	181·8	+3·8	−1·2	3·6	±1·8	0·5	0·3
Near Stubbington.. ..	Up	40	139·4	−0·1	+2·1	4·8	−2·6	0·2	0·2
,, ,, ...	Down	38	139·1	−0·4	+1·1	4·2	−2·3	0·8	0·2
Hill Head (Beach).. ..	Up	25	121·2	−1·9	+2·2	4·2	+3·0	0·3	0·2
,, ,, ,, ...	Down	38	119·5	−3·6	+2·9	7·8	−4·3	0·7	0·2

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TABLE.—*Summary of Observations on Fort Monckton (5AY) during Test on Open-Wire Screen September to December*, 1927—continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Position of Observation.	Condition of Screen.	No. of Observations.	Bearings.			Variation.		½ Width of Signal Minimum.	
			Mean.	Error of Mean.	Direct Minus Reciprocal.	Extent of.	Extreme from Mean.	Mean of 1st Min.	Mean of 2nd Min.
			degrees.	degrees.	degrees.	degrees.	degrees.	degrees.	degrees.
Other Land Observations—									
Slough	Up	468	208·5	+1·7	+1·1	5·4	±2·7	0·4	0·4
,, ...	Down	111	208·7	+1·9	+1·0	4·2	−2·3	0·7	0·3
Teddington	Up	1,468	218·1	+0·1	−0·3	3·0	−2·1	0·5	0·4
,, ...	Down	665	217·8	−0·2	−0·7	3·0	−1·8	0·8	0·3

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the proximity of the sea at this point at different states of the tide. The increase in observed bearing mentioned above does not necessarily mean an increase in the error, which varies at the different sites selected.

Referring to column 6 in the table, which indicates how accurately the direct and reciprocal bearings agree with each other (after making the necessary 180° correction), it is seen that in the majority of cases there is a definite improvement with the screen removed.

As against this, however, the results given in columns 9 and 10 confirm the general impression previously described as to the effect of the screen on the quality of the signal minima. For it is seen that, while at sea, the minima are equal and fairly sharp in all cases, at the land positions with the screen removed, one of the minima is considerably sharper than the other. The erection of the screen had the effect of equalising these two minima, although both were then only moderately sharp.

Conclusions

It is to be concluded that on the whole the presence of the screen at the beacon effected a slight improvement in the symmetry of the radiation for bearing observation purposes. The advantage gained is, however, seriously masked by the errors observed over land and sea, which appear to be definitely due to the site at Fort Monckton. Since these experiments confirm all previous experience with this beacon, it does not seem desirable to carry out any further work in this direction until a beacon on an improved site is available. The opportunity will be taken in the immediate future of studying the land and coastal errors at Fort Monckton in more detail.

An interesting practical point arising from this investigation is that since the presence of an open-wire screen does not have any detrimental effect on the radiation from a rotating beacon, it should be possible to protect such a beacon from lightning by enclosing it within a symmetrical screen of vertical wires. These wires must be short compared with a quarter of the wave-length employed and can be bonded together and earthed only at a point well below the beacon loop.

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PREFATORY NOTE

THE present report gives the results of wireless observations carried out under the general supervision of the Radio Research Board during the Eclipse of the Sun on 29th June, 1927. Most of the results have already been referred to in published papers describing the general work of the Board on the Propagation of Waves, but it was considered that it would be convenient to collect them together in a single Report.

The Section of the Report dealing with Long-Wave observations has been prepared by Mr. J. Hollingworth, M.A., D.Sc., M.I.E.E., that on medium-wave observations by Professor E. V. Appleton, D.Sc., F.R.S., and that dealing with Direction-Finding observations by Dr. R. L. Smith-Rose, A.M.I.E.E. In addition to the work carried out under the direct supervision of the Board, a series of observations was made by Professor E. W. Marchant and Mr. E. Youel at Liverpool University on signals from Stavanger (Norway) and a note on these is included.

Thanks are due to the Norwegian Radio Authorities, and to the Compagnie Radio-France for arranging the transmissions on long waves from Stavanger and St. Assise respectively, and to the British Broadcasting Corporation for arranging the transmissions on the medium waves.

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WIRELESS OBSERVATIONS DURING THE ECLIPSE OF THE SUN 29th JUNE, 1927

Introduction

ADVANTAGE was taken by the Radio Research Board of the opportunity provided by the solar eclipse on the 29th of June, 1927, to carry out investigations with the object of studying the influence of the solar eclipse on the characteristics of wireless transmissions generally. Since it was considered essential that the apparatus used should be capable of giving comparatively precise quantitative results, the experiments made were limited to long waves (12,000–14,000 metres) and to medium waves (300–500 metres).

The positions of the transmitting and receiving stations which took part in the observations are indicated on the map (Fig. 1). Early in the preparations for the experiments it was pointed out by Dr. E. H. Rayner that if the vagaries of wireless reception were due to the influence of an ionised layer situated at a considerable height above the ground, the total eclipse at such a height would not take place in the same region in England as the eclipse on the ground because of the low altitude of the sun at the time of the eclipse. An accurate computation made by Dr. J. L. Comrie showed that the intersection of the moon's shadow with the surface concentric with the earth, and at a height of 60 miles, would be situated above a belt lying about 100 miles south east of the central eclipse track on the ground. Dr. Comrie also showed that the eclipse at that level would pass across England in two minutes, beginning at 0520,* and thus leave the east coast before the centre of the shadow at the earth's surface arrived from the west at the Welsh coast (0523). These considerations were taken into account in arranging the positions of the various transmitting and receiving stations.

In addition to the observations on the intensity, phase and other characteristics of the components of the resultant fields of the waves at the receiving stations, a series of direction-finding observations were also carried out.

Long-Wave Observations

The long-wave observations under the direction of the Radio Research Board consisted of :—

(*a*) Observations on St. Assise ($\lambda = 14{,}350$ metres) at the Radio Research Station, Ditton Park, near Slough, by Messrs. J. Hollingworth and R. Naismith, and at Aberdeen by the late Dr. Fyvie

(*b*) Observations on Stavanger ($\lambda = 12{,}100$ metres) at Exeter.

* All times in this paper are G.M.T.

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The transmissions were planned with a view to making observations :—

(*a*) On signals crossing the band of totality at a large angle in such a way that the band of totality lay roughly midway between the transmitting and receiving stations ;

(*b*) On signals which remained outside the band of totality altogether ; and

(*c*) On signals which, as nearly as possible, had travelled along the path of totality.

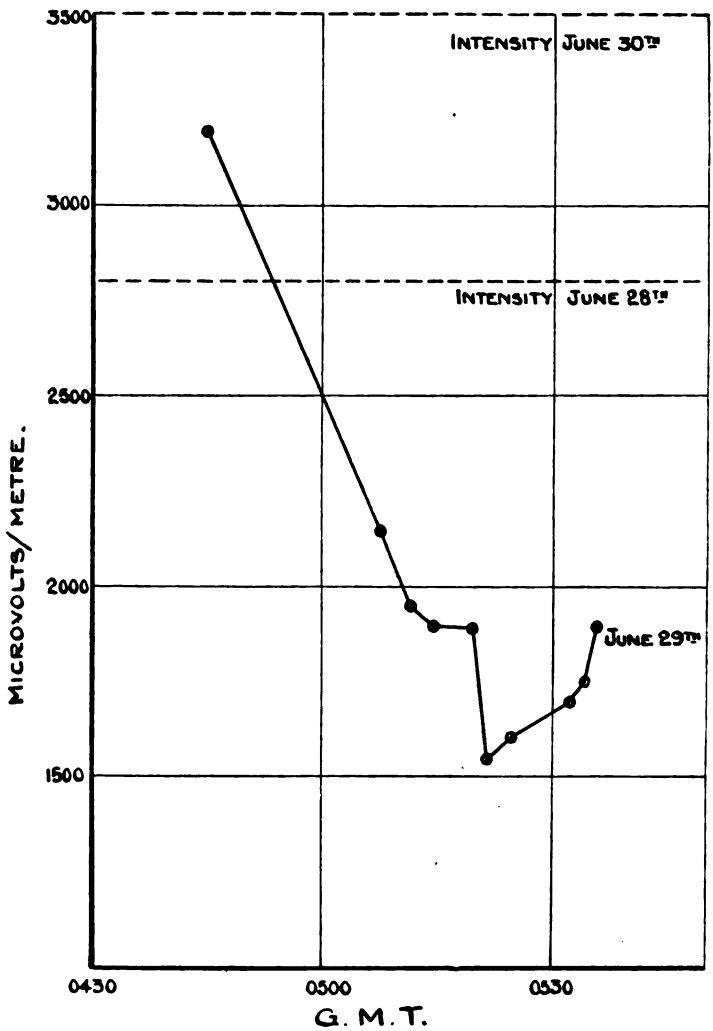

FIG. 2.—*Graphs of signal intensity from St. Assise received at Slough on June 28th, 29th and 30th, 1927.*

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The actual curves giving the results of the observations carried out at Slough, Exeter and Aberdeen are given in Figs. 2, 3 and 4. From a rough examination of these it is clear that the effects of the eclipse were very marked.

Observations on the days preceding the eclipse showed that, in the case of long waves, the effect of sunrise had passed off altogether before the eclipse began. Incidentally, it may be remarked that a series of observations taken near sunrise on the morning of the eclipse showed that daytime conditions were re-established by 0330.

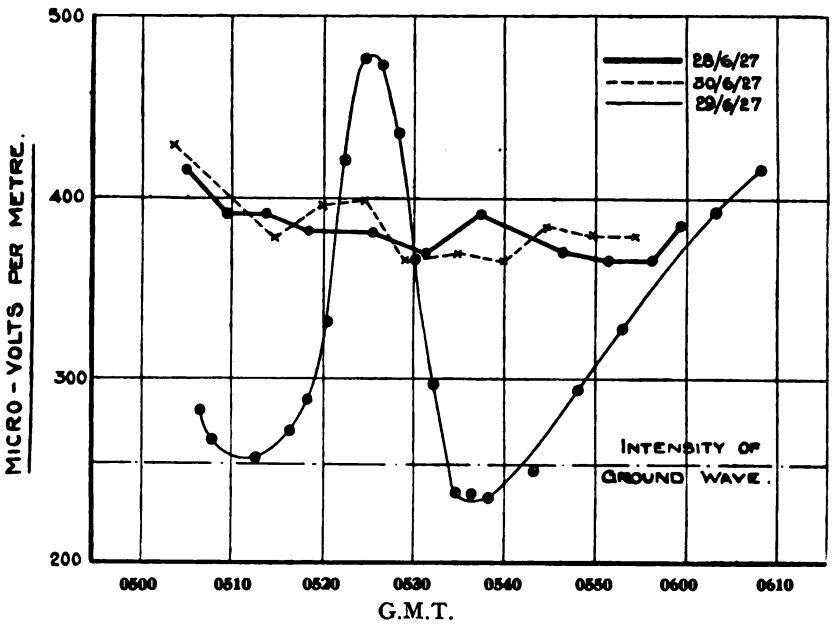

FIG. 3.—*Graphs of signal intensity from Stavanger received at Exeter on June 28th, 29th and 30th, 1927.*

Assuming that the resultant signal at the receiving station was due to a combination of a direct ground wave and of a downcoming wave deviated by the upper atmosphere, the mere rise and fall of intensity gives but little information regarding the phenomena of wave propagation without some knowledge of the phase relations between the component rays involved. The previous work of the Radio Research Board on the propagation of waves has made it clear that mere numerical repetition of the same value of received intensity from a station on different occasions does not necessarily imply identical physical conditions of wave propagation, as it may be caused by the simultaneous change of two factors such as intensity and phase in such a way as to leave their result unaltered.

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From the work of Appleton and Smith-Rose there appear to be three factors involved :—

(i) Attenuation ;

(ii) Phase relation between the ground and downcoming waves ;

(iii) Abnormal polarisation of the downcoming waves.

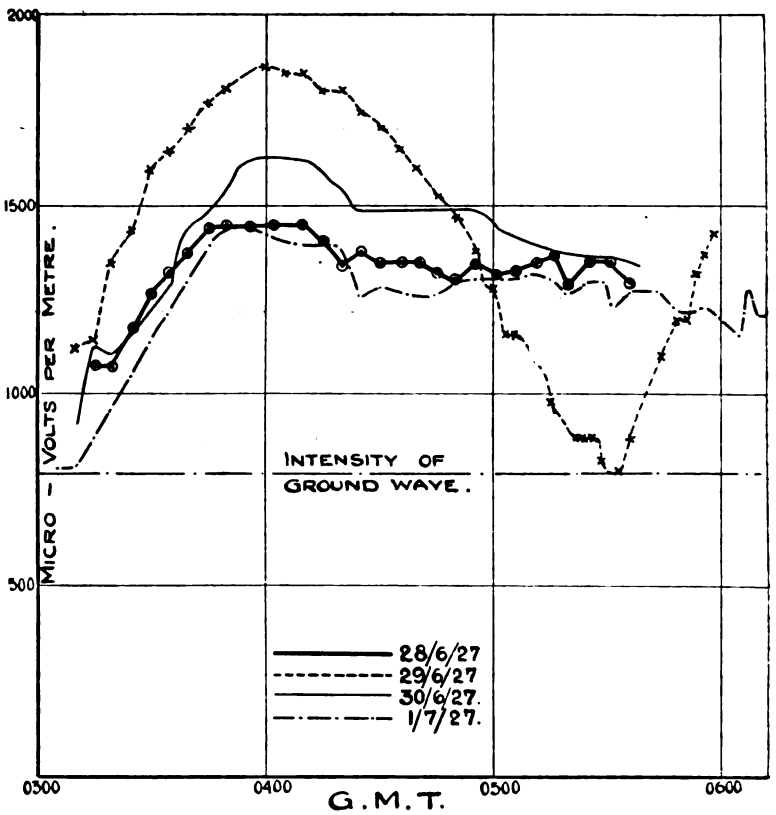

FIG. 4.—*Graphs of signal intensity from St. Assise received at Aberdeen on June 28th, 29th, 30th and July 1st, 1927.*

Just previously to the eclipse, carefully designed apparatus was developed at the Radio Research Station at Slough, which gave the means for examining these factors separately with a considerable degree of accuracy. This apparatus, which is now being employed in the general analysis of long-wave propagation, has been described elsewhere.* Briefly, the measurements taken in the apparatus employed are the intensity in two frame aerials at right angles inclined at 45° to the actual direction of the transmitting station. The aerials are joined to the field coils of a radio-

* *J. Sci. Instr.*, 1928, **5**, 1.

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goniometer, and the phase difference between the E.M.F.s in the two coils is obtained by de-tuning one of the aerial coils until a sharp minimum is obtained when the search coil of the radiogoniometer is rotated. An extended series of observations at sunrise and sunset on St. Assise at Slough has been carried out with this apparatus, and a full analysis of the received waves at these times has been made. The observations have been described in a paper submitted to the Royal Society, and the results obtained from them have been used to confirm the interpretation of the results obtained during the eclipse, which are summarised below.

Discussion and Summary of Results

Slough.—From a study of the sunrise run taken at Slough on the morning of the eclipse, it was clear that when normal day conditions were re-established by the disappearance of abnormal polarisation, the ground and downcoming waves were out of phase with one another. At the same time the measurements showed clearly that at Slough during the eclipse period there was no sign whatever of the re-appearance of abnormal polarisation ; so that the only possible cause of a decrease in total intensity must have been an increase in the downcoming wave, which was in opposition to the ground wave, i.e., an increase in reflection coefficient. The figures gave an increase from 0·13 to 0·22, which is consistent with the results obtained from sunset runs. It appears that the reflection coefficient, which in June is often nearly zero during the day, rises during the earlier part of the sunset period to a value between 0·2 and 0·3, where it remains constant for some time, and rises again some time much after sunset.

The results at Aberdeen and Exeter are more difficult to interpret, there being no apparatus at either of these stations capable of giving wave analysis.

Aberdeen.—Owing to new apparatus being in use which had not been fully calibrated, the absolute values at Aberdeen are of less accuracy than the relative values. The former are, however, sufficient to show that the signal intensity for almost the whole time was above the ground-wave value (790 μv/metre), and consequently the explanation given for the effect at Slough is no longer valid. Without more detailed knowledge of phases, &c., such as were obtained at Slough, it is impossible to give a definite explanation of the effect, although the most probable seems to be a slight change in layer height. The high value reached at 0400 is probably entirely unconnected with the eclipse, as at this time the sunrise effect had hardly passed off and it represents nothing more than the normal day-to-day difference which frequently occurs.

Exeter.—The result at Exeter appears to be of a slightly different nature. As at Aberdeen, all intensities are above the ground-wave

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value (255 μv/metre) and the same gradual drop occurred. Superimposed on this, however, was the very abrupt rise over a short period covering totality during which the value reached was so high that it can be only accounted for by a rise in reflection coefficient to a value of about 0·3 since the waves here are nearly in phase. As at Aberdeen, however, the absence of phase and polarisation observations make more detailed analysis impossible. It should be noted that the direction of this transmission was practically along the line of totality, whereas the others were across it.

Summary.—In two cases there appears to have been direct evidence of a rise of reflection coefficient, and in one case this was definitely unaccompanied by any abnormal polarisation. It seems, therefore, that the effect of the eclipse on long waves was that of a minor sunset in which only the preliminary phenomena of a normal sunset occurred, totality not lasting long enough for the complete effects to occur. It is also clear that the effects were not confined to the totality band, which was altogether outside the path of the St. Assise—Slough transmission. This is in agreement with the effect previously noted in sunset runs, that a rise in reflection coefficient occurs as the first effect of sunset, before the actual instant of sunset.

Observations on Medium Waves

The methods used in the observations on medium waves were those suitable for investigating the characteristics of waves which have been deviated through large angles by the ionisation in the upper atmosphere. These methods, which have been developed mainly at the Peterborough Radio Research Station, have been previously described,* so that the present paper deals mainly with the results obtained on the occasion of the eclipse and only incidentally with experimental details. The observations were made on special transmissions from the stations of the British Broadcasting Corporation. Those special transmissions were of two types :—

(*a*) Transmissions of an unmodulated carrier wave the wavelength of which could be changed continuously through a small range. The resulting signal maxima and minima due to interference between ground and atmospheric waves, were measured at receiving stations fitted with Einthoven galvanometers working with photographic registration. From the photographic records it was possible to deduce the relative amplitudes of atmospheric and ground waves and also the equivalent height of the ionised layer responsible for bending back the atmospheric waves. Such transmissions took place from the Newcastle and Birmingham stations.

* *Proc. Roy. Soc.*, 1925, A, **109**, 621 ; *ibid.*, 1926, **113**, 450 ; *ibid.*, 1927, **115**, 291 and 305.

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(*b*) Transmissions of a carrier wave of constant wave-length unmodulated except for the announcement of time signals. The signal variations at various distances were studied by observers using galvanometric methods. Such transmission took place from the London and Manchester broadcasting stations.

Since observations made with transmission of type (*a*) can be made within five seconds, and also yield much fuller data than do simple signal measurements, it was decided that such transmissions should be used to investigate whether there were any marked differences between the phenomena experienced in the region of eclipse at the ground and in the region of eclipse at the ionised layer. The positions of the B.B.C. transmitters left little choice in the matter of sites for such tests, and accordingly the phenomena in the region of eclipse at the ground were studied, using the Newcastle transmitter working in collaboration with a receiving station at the Liverpool University Engineering Laboratory using an aerial and other facilities kindly provided by Professor E. W. Marchant. For similar observations in the region of eclipse at the ionised layer the Birmingham transmitter was used with the Peterborough Radio Research Station as the receiving station.

Observations on the transmissions of type (*b*) were made at St. Albans, Nottingham, Peterborough, Newcastle-on-Tyne, Gigglewick, Aberdeen and Slough.

All transmissions were on wave-lengths within the broadcasting range, that is between 300 and 500 metres.

By the kind co-operation of Inspector of Wireless Telegraphy of the General Post Office, arrangements were made for shore to ship working to be reduced to the minimum necessary in case of distress signals, and all ships were invited to refrain as far as possible from transmitting on the morning of the eclipse. The result of this was that unusually favourable conditions were obtained for the experiments, so that at Peterborough, where the more elaborate measurements were made, there was not the slightest interruption of observations during the eclipse period due to ships. There was, however, considerable interference at times due to foreign broadcasting stations.

The observations made on both types of transmission will now be described, and, to reduce the number of cross-references, the more detailed discussion of any series of observations is given with the observations. A short general discussion of the agreement between the results of the different sets of measurements then follows.

Experimental Results

(*a*) *Observations at Peterborough on the Birmingham Transmissions*

These observations were made by Professor E. V. Appleton and Dr. M. A. F. Barnett, with Mr. R. D. Gander acting as assistant

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for the photographic work. A large single-turn vertical loop in the plane of propagation and a vertical aerial along the axis of the loop were used as antennæ. By means of a switching arrangement the signal variations consequent on a wave-length change at the transmitter could be recorded using loop and vertical aerial alternately. From the interference "fringes," recorded as signal variations by means of a high-frequency amplifier and Einthoven galvanometer, the following quantities were determined :—

(i) the intensity of the normally polarised component of the downcoming waves relative to that of the ground waves, which is assumed to be constant. This was deduced from the amplitude of the "fringes" recorded when the loop aerial was used ;

(ii) the equivalent path difference* between ground and atmospheric waves, from which the equivalent height of the deviating stratum can be calculated by simple triangulation. The path difference was determined from the number of "fringes" produced by a known change of wave-length ;

(iii) the angle of incidence of the downcoming waves.† This was deduced from the relative amplitudes of the "fringes" recorded using the loop and vertical aerial in rapid succession.

Many measurements of this type have previously been made during the course of and after a normal sunrise, and, as it has been found that conditions may vary very markedly from week to week, it was decided that comparison observations should be made on the day preceding and the day following the eclipse. Moreover, since the eclipse took place so early in the morning, it was considered necessary to begin observations before the normal sunrise, as it seemed possible that the effects of sunrise might not have disappeared before the effect of the eclipse became appreciable. As sunrise occurred at 0347 on the day of the eclipse, observations therefore began on each of the three days at 0200.

Figs. 5 and 6 show the variation of the intensity of the downcoming ray (expressed as a fraction of the ground ray intensity) with time on the morning before (28th June) and the morning of the eclipse (29th June) respectively. The first is quite typical of the phenomena experienced during many sets of sunrise observations. The amplitude of the downcoming ray, though varying a good deal, is seen to be reduced, in general, as sunrise approaches. This reduction in amplitude was, as usual, accompanied by the disappearance of the secondary maxima and minima superimposed on the main "fringes." At 0330, however, there was a marked

* Vide *Proc. Roy. Soc.*, 1926, A, **113**, 450.

† Vide Method ii, *Proc. Roy. Soc.*, 1927, A, **115**, 298.

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increase in the amplitude of the downcoming ray, though the "fringes" still remained smooth, indicating the presence of only one downcoming ray or of a series of downcoming rays with atmospheric paths of about the same length. After sunrise the downcoming ray was much reduced in intensity and remained barely detectable for the remainder of the morning's observations. Unfortunately, there was a break in the readings after sunrise due to transmitter breakdown, but, from our previous observations, we can say that there is little doubt that the value of H_1/H_0 was approximately constant from 0415 to 0630.

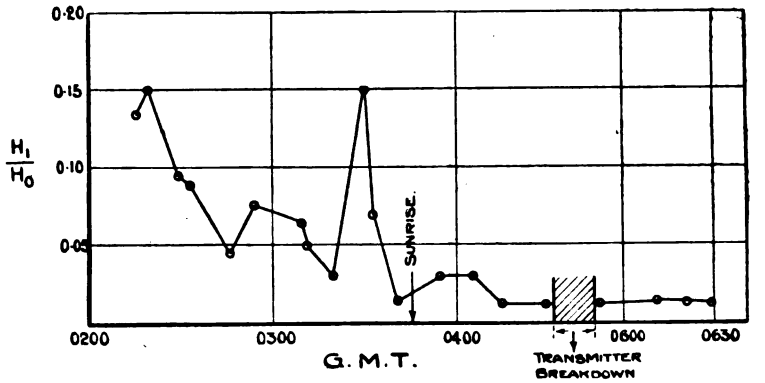

FIG. 5.—*Graph showing the ratio of the intensities of downcoming and ground waves from Birmingham observed at Peterborough, June 28th,* 1927.

On the morning of the eclipse a similar cycle of events took place and normal daytime conditions had been reached before the effect of the eclipse was noticeable. At 0510 a slight increase

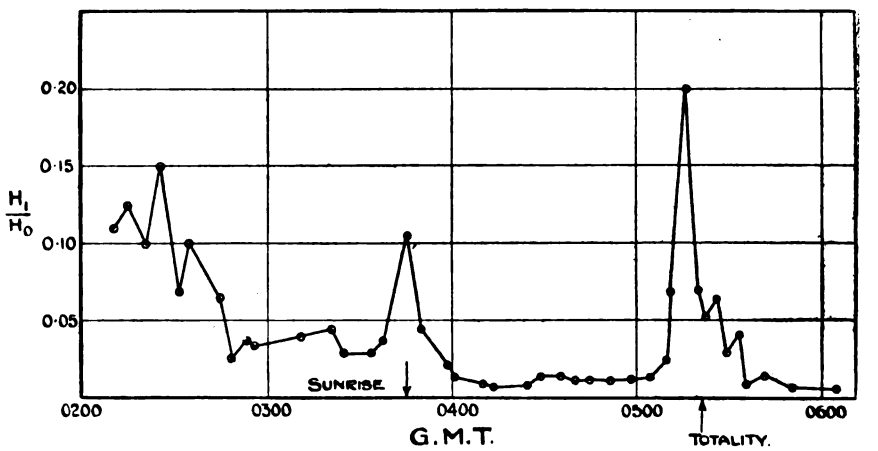

FIG. 6.—*Graph showing the ratio of the intensities of downcoming and ground waves from Birmingham observed at Peterborough, June 29th,* 1927.

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in the amplitude of the downcoming ray was observed followed by a remarkably large increase to a value 16 times that corresponding to daytime conditions. At the same time as this increase in amplitude was recorded, the observations show that the equivalent path difference between ground and atmospheric waves had increased, while the angle of incidence of the downcoming waves at the ground had been reduced. The first of these effects is illustrated in Fig. 7 in which $\frac{\delta n}{\delta \lambda}$, the number of fringes per metre wave-length change (a quantity which is proportional to the path difference (D) between ground and atmospheric rays) is plotted as a function of the time. The increase in the value of $\frac{\delta n}{\delta \lambda}$ caused by the eclipse is

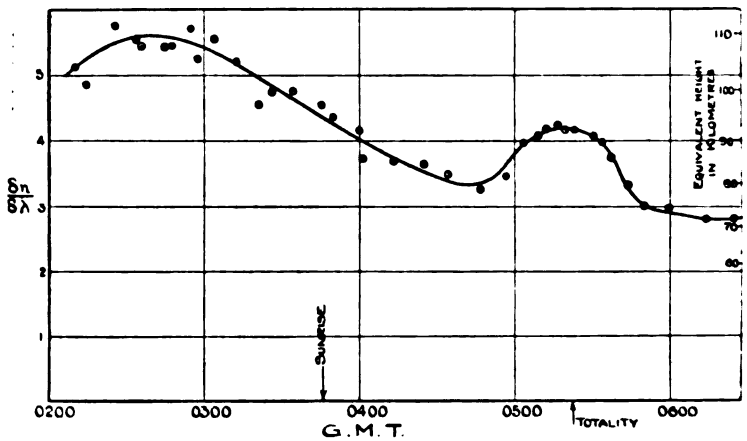

FIG. 7.—*Graph showing the number of fringes per metre change in wave-length observed at Peterborough on the transmissions from Birmingham, June 29th,* 1927.

equal to an increase in the equivalent height of the layer from 75 km. to 94 km. The decrease in the angle of incidence at which the downcoming waves reach the ground also indicates an increase in the height of the stratum responsible for deviating the waves. It may therefore be concluded that the increased intensity of the downcoming ray was due to the removal of ionisation in the lower layers of the atmosphere together with an increase in the height at which the waves were turned back. The large " fringes " recorded during the period of the eclipse effect were, however, smooth and therefore similar to those recorded about 0345 rather than to those representative of night-time conditions when " secondaries " are almost always present. The effect of the eclipse must therefore be regarded as only a partial return to proper night-time conditions.

A comparison of Figs. 6 and 7 show that the detectable effect of the eclipse lasted slightly longer in the case of the measurements of equivalent height than in the case of the measurements of the

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intensity of the downcoming ray. Also in the case of the height measurements the maximum value was registered just about totality at the ionised layer, while the greatest amplitude of the downcoming ray was detected before totality.

(*b*) *Observations at Liverpool on the Newcastle Transmissions*

The observations here were made by Mr. G. A. Ratcliffe with Mr. W. C. Brown acting as photographic assistant. Owing to the greater distance of transmission and consequently weaker signals with increased liability to interference, the observations were relatively much more difficult than in the case of the Peterborough measurements. As the receiving site did not permit of a loop and aerial combination similar to that in use at Peterborough, an ordinary vertical aerial was used and attention concentrated on the determination of the equivalent height of the layer.

Unfortunately, during the middle of the eclipse period these observations were rendered quite impossible by interference from a neighbouring amateur transmitting station. The result of this was that no observations could be made during the critical period of 0450 to 0525 on 29th June. But the readings that were obtained at the beginning and end of the eclipse period entirely confirm the Peterborough results in that at the beginning of the period the equivalent height was increasing and at the end was decreasing, and in both cases the heights registered were higher than those measured at the same time on the following day.

As a result of the amateur interference we are therefore unable to make the interesting comparison suggested by Dr. Rayner between the effects of the eclipse at the ground and at the ionised layer.

(*c*) *Observations on the Constant Wave-Length Transmissions from London and Manchester*

Observations on the signals received from the steady transmissions from London and Manchester were made by Miss B. Saltmarsh at St. Albans, Mr. H. B. Old at Nottingham, Mr. O. Darbyshire at Newcastle, Mr. S. R. Wright at Giggleswick and by Dr. W. W. Fyvie at Aberdeen. Some of these observers had been supplied with galvanometers by the Radio Research Station under a scheme of amateur co-operation in the study of signal fading. Readings of rectified signal current were taken at these receiving stations every ten seconds throughout each alternate ten minutes during the period of the transmissions, except on the occasion of the eclipse when readings were taken every five seconds continuously. Although the apparatus used was of the simplest character, the results obtained by these observers are very valuable, for they confirm, in a remarkable way, the variations in downcoming ray intensity detected at Peterborough. Although the results obtained at all stations have individual points of interest, it must suffice

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here to consider mainly two series of observations which, because of the distances from the transmitter at which they were made, illustrate most simply the main effects. The two cases chosen are the observations made by Mr. Old at Nottingham and those made, by Mr. Wright at Giggleswick. Both were made on the 2 LO (London) transmissions of 365 metres wave length.

At Nottingham a strong ground wave was received and the presence of a downcoming ray was shown by the small variations of intensity which took place about a constant mean value. On the mornings before and after the eclipse such variations were present when the transmission began (0330), but gradually became less noticeable as the downcoming ray grew weaker, till finally a steady signal was received. To make these results comparable in some way with those made at Peterborough, a calculation has been made from Mr. Old's readings of the mean departure of signal from the daytime value, which gives us an inferior limit for the

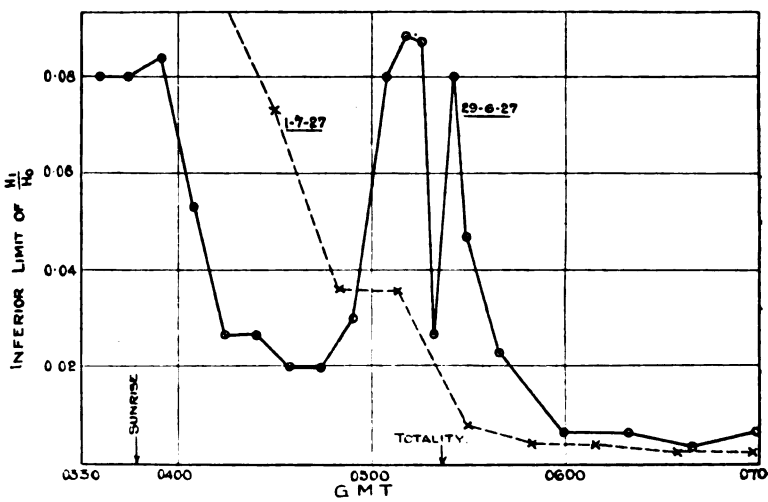

FIG. 8.—*Graph showing the ratio of the intensities of the downcoming and ground waves observed at Nottingham on the transmissions from London 29th June and 1st July,* 1927.

magnitude of the downcoming ray intensity relative to that of the ground ray. The variation of this ratio with time for a typical morning run on July 1st, 1927, is shown in Fig. 8. The results calculated in the same way, for the morning of the eclipse, are also shown in the same figure for comparison. On the morning of the eclipse the same fall of downcoming ray intensity was observed at the beginning of the observations as on the other days. The effect of the eclipse was to increase the fading very noticeably as is shown by the large increase in the magnitude of the downcoming ray. The results exhibited in Fig. 8 may be compared with the Peterborough observations shown in Fig. 6. Exact

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agreement between the numerical values of the ordinates in the two cases cannot of course be expected, for the Nottingham values are only inferior limits* for the ratio $\frac{\text{downcoming ray intensity.}}{\text{ground ray intensity}}$

It may be noted that in this series of observations, as in the case of the Peterborough measurements, the greatest amplitude of downcoming ray was detected before totality.

In the case of the observations made at Giggleswick on the London transmissions, we are dealing with a case in which the ground ray was practically negligible, so that reception was carried out almost solely by means of the indirect ray or rays. Thus the signal current readings, with no further reduction, may be taken as an indication of the strength of the downcoming waves. In Fig. 9 are shown the signal current variations obtained on the morning of the eclipse. This may be compared with the readings on the

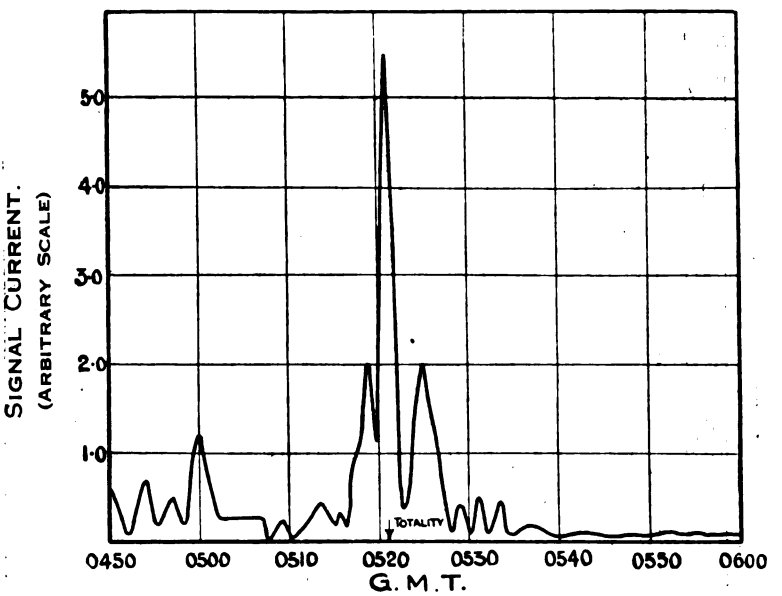

FIG. 9.—*Graph showing the variation of received signal current at Giggleswick from the London transmitting station, 29th June, 1927.*

other days of the test which were on the average 0·06 unit (i.e., practically zero) on the same scale for the same period. It is thus seen that, although on normal days the intensity of the down-

* This arises from the fact that it is not possible to be sure that each signal maximum corresponds to a state of affairs in which ground and atmospheric waves are in phase, and also to the fact that a vertical aerial was used in Nottingham on which only the vertical component of the electric force of the downcoming wave is effective. Thus the Nottingham values should all be too small.

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coming ray was negligible at this period of the day, the effect of the eclipse was to increase very markedly this intensity. A similar increase of signal intensity was reported at the more distant station of Aberdeen, at which station the normal daytime signal is negligible. In the case of the Giggleswick observations the maximum value

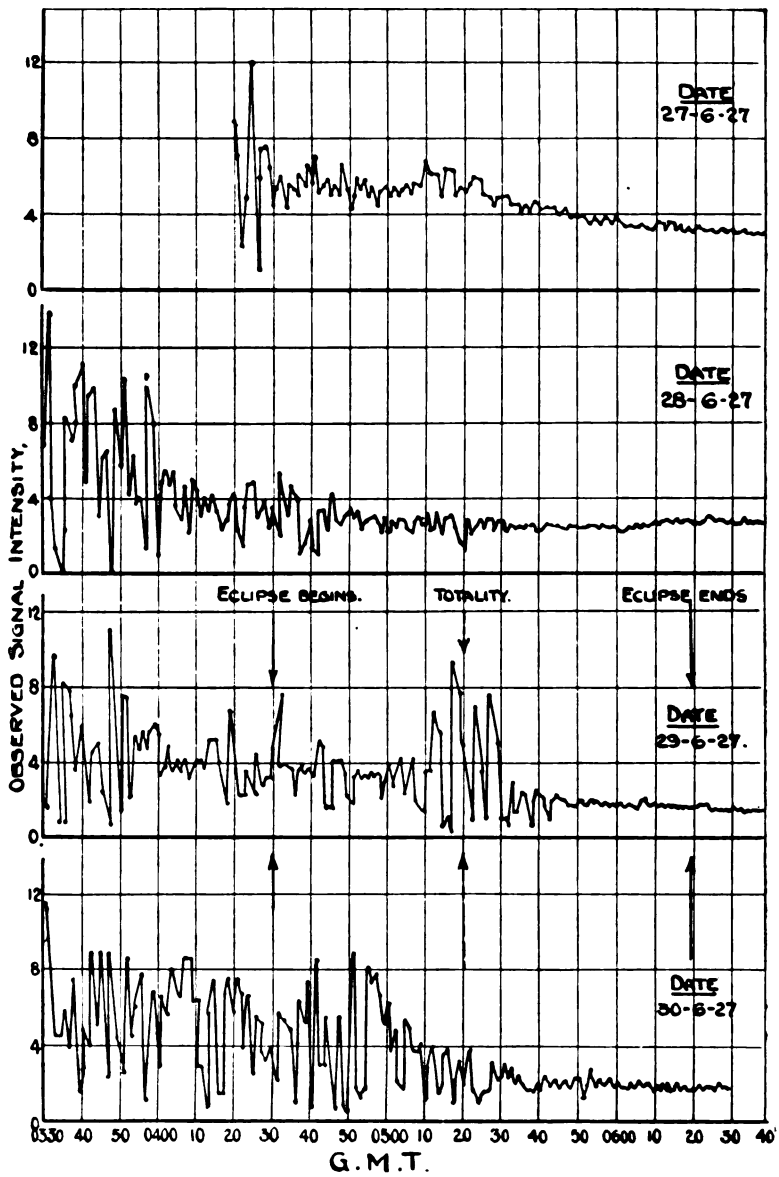

FIG. 10.—*Graphs of signal intensity of the transmissions from Manchester observed at Slough on June 27th to 30th*, 1927.

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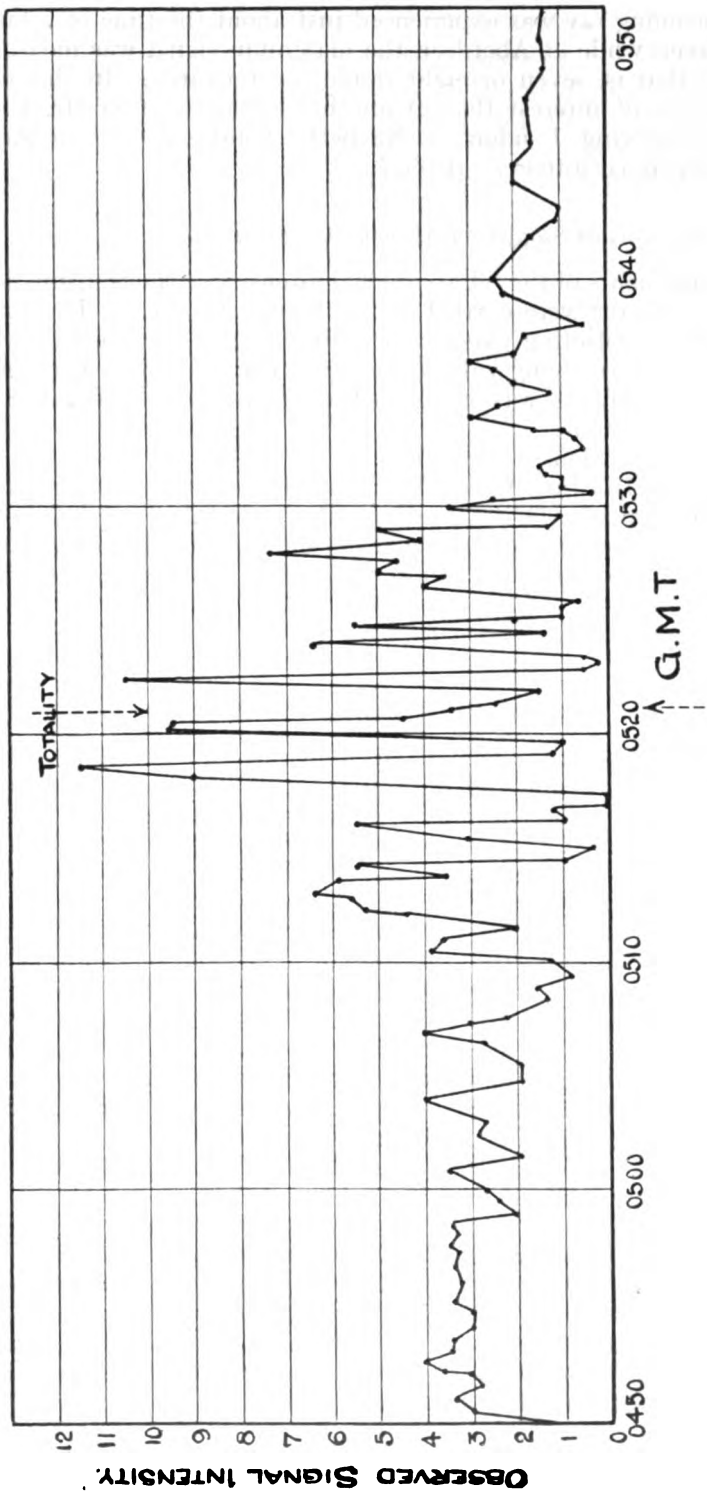

FIG. 11.—*Enlargement of the graph in Fig.* 10 *for the period of the eclipse only, June 29th,* 1927.

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of downcoming ray was experienced just about the time of totality at the layer, while at Aberdeen the maximum signal was measured at 0529, that is, seven or eight minutes afterwards. In this connexion it is of interest that at another distant station Mr. E. A. Anson, observing London at Narbeth, Pembrokeshire, found a maximum signal intensity at 0527.

(d) Observations at Slough on Manchester Transmission

Measurements of the relative signal intensity of the transmissions from Manchester were carried out at Slough by Mr. G. H. Munro employing a reflecting galvanometer inserted in the anode circuit of the second rectifying valve of a supersonic receiver. The entire receiving apparatus was calibrated over the necessary range of intensity variations.

The observations were made from 0300 to 0630 on the mornings of 27th June to 1st July, and the results are summarised in Fig. 10. In Fig. 11 the graph for the 29th June, the day of the eclipse, is reproduced to a larger scale, showing the intensity variations for a short interval before and after totality. This curve shows very clearly the large increase of variations which lasted for about 10 minutes on either side of totality.

Discussion and Summary of Results

The observations summarised above show that the eclipse produced a very definite effect on the properties of the ionised layer responsible for deflecting waves of 300–400 metres back to the ground. The most striking effect was the large increase in the intensity of the downcoming ray, which was detected at both near and distant receiving stations. We may ascribe this effect partly to the increase in height of the stratum responsible for bending back the waves and partly to the rapid removal of ionisation in the lower layers of the atmosphere consequent on the removal of the solar ionising agents. The increase in the height of the stratum was so large as to be detectable by the methods described. The results as a whole seem to suggest that the more southerly receiving stations experienced the maximum eclipse influence a little earlier than the northern stations. A striking feature of the observations was the short time the eclipse effect lasted, this period varying from 20 to 50 minutes at the different stations, while the total time taken for the moon's shadow to pass across the sun was nearly two hours. This means that quite an appreciable fraction of the sun's radiation may be cut off before the effect can be detected by wireless methods. In conclusion, it may be mentioned that the morning after the eclipse was exceptional in that night-time conditions seemed to persist for such a long time after sunrise. The records of all stations show evidence of this.

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Direction-Finding Observations

Description of Experiments

Direction-finding observations were made during the week of the eclipse of the sun at Teddington, Bristol, Leyburn and Slough. The experiments were arranged by Dr. R. L. Smith-Rose assisted by Messrs. R. H. Barfield, G. H. Munro, E. L. Hatcher and A. C. Haxton.

The observations at each of these stations were limited to one transmitting station only; thus Teddington observed Rugby (long wave); Bristol and Slough the Manchester B.B.C. station, and Leyburn the London B.B.C. station. The plan-paths of the waves for these transmitters working to these receivers can be seen in the map (Fig. 1), which also shows the approximate position of the shadow belt centre line at the altitude of the Heaviside layer. It will be seen that both the Manchester–Slough and London–Leyburn transmissions are roughly bisected by this line.

Observations were made between 0330 and 0730 on 27th to 30th June and 1st July. Except in the case of Teddington, which during part of the time made observations upon the ordinary traffic transmissions from Rugby, they were carried out on transmissions specially arranged for the purpose.

Simple rotating coil direction finders, capable of detecting variations in bearing of less than one degree, were employed at all stations. Readings were taken of the apparent bearing of the transmitting station once every minute during each of the four-hour periods, except on the actual day of the eclipse, when the frequency of observation was increased to once per half minute for a short period during maximum observation.

Experimental Results

(*a*) *Long-Wave Observations.* ($\lambda = 18{,}750$ *metres*)

The results of the Teddington–Rugby observations showed clearly that the ordinary night variations did not appreciably abate until at least an hour after the time of totality, so that any effect due to the eclipse was completely masked. The curves of variations for this case have, therefore, not been reproduced in this report.

(*b*) *Medium-Wave Observations.* ($\lambda = 361$ *and* 385 *metres*)

The results of these observations are shown in the curves, Figs. 12 to 14, which form a complete record of the experiments, except for the last hour and a half of each period, by which time the variations of bearing and intensity had already definitely ceased for some time. In the case of the directional observations, the errors, without regard to sign, are plotted with respect to time.

In Fig. 15 are reproduced portions of the graphs given in Fig. 14, showing the variations of bearing of signals from

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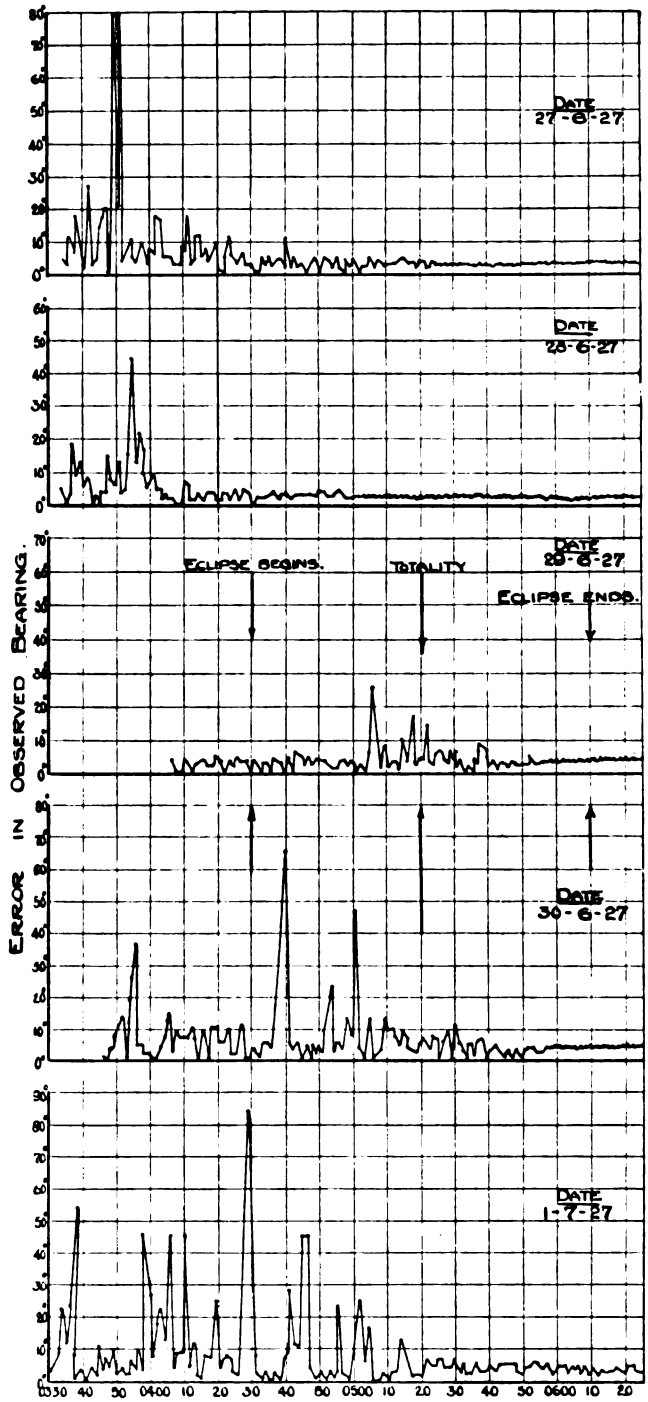

FIG. 12.—*Graphs showing the variations of the errors in apparent bearing of Manchester observed at Bristol, June 27th to 30th and July 1st, 1927.*

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Manchester as observed at Slough for a short interval before and after totality of the solar eclipse. This is drawn to a larger time scale and is selected as exhibiting in the most favourable manner the apparent correlation between variations and the eclipse.

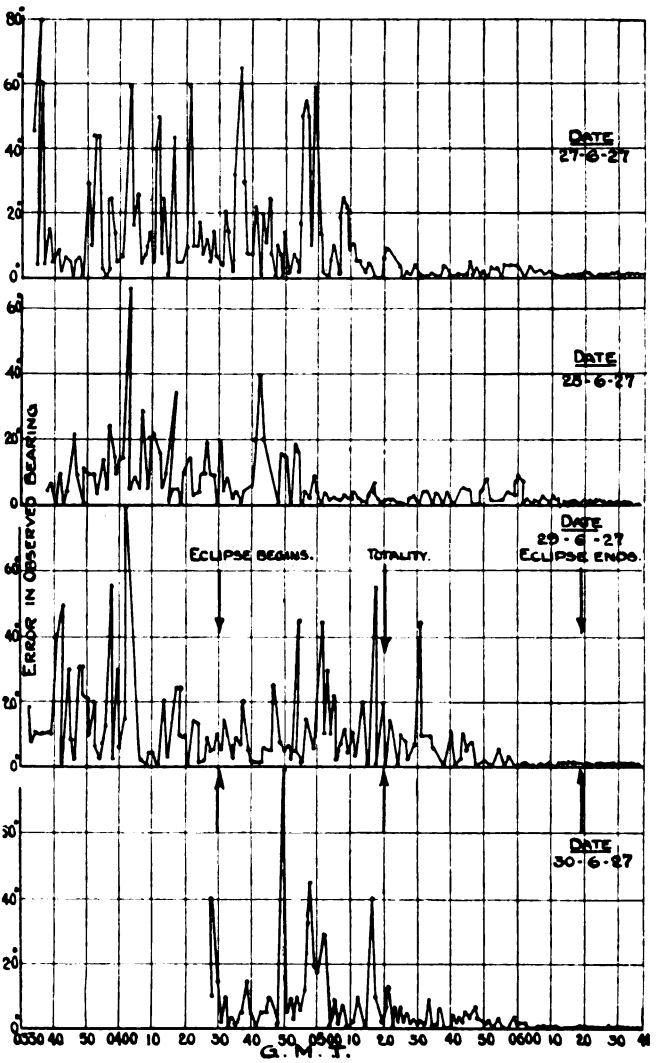

FIG. 13.—*Graphs showing the variations of the errors in apparent bearing of London observed at Leyburn, June 27th to 30th,* 1927.

Conclusions

An inspection of the main series of curves (Figs. 12 to 14) shows at once that they constitute fairly strong evidence of a definite

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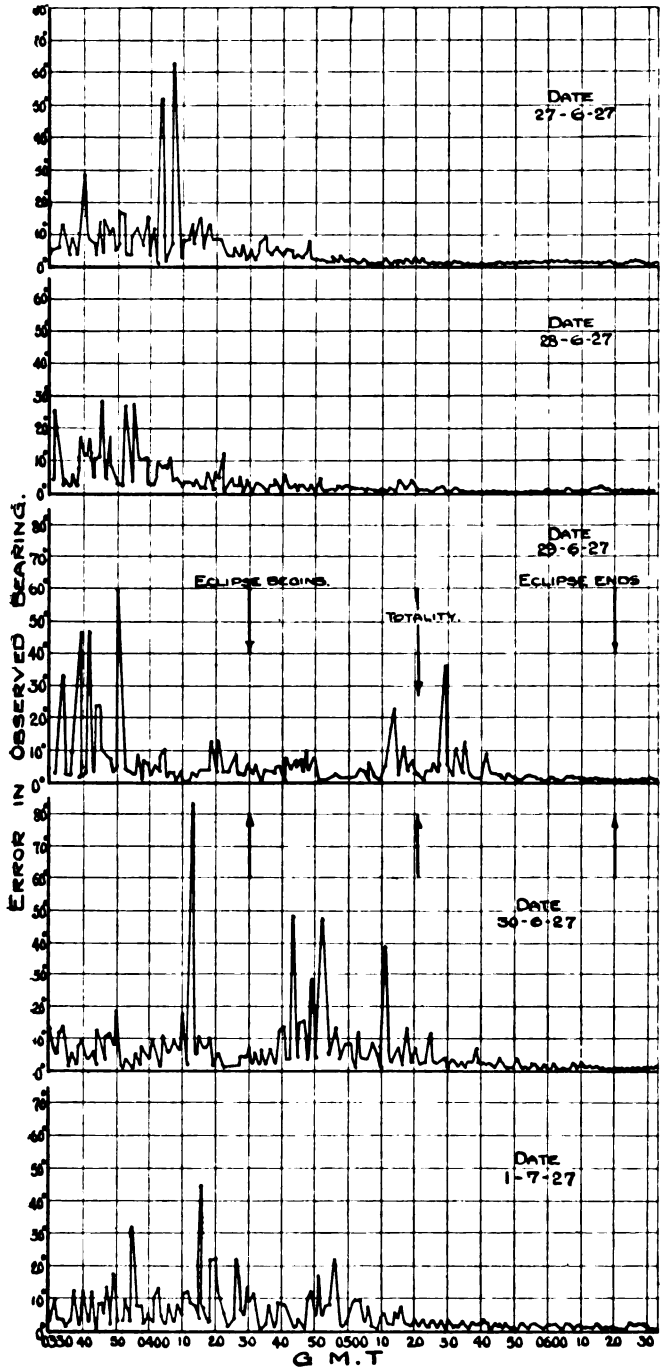

FIG. 14.—*Graphs showing the variations of the errors in apparent bearing of Manchester observed at Slough, June 27th to 30th and July 1st, 1927.*

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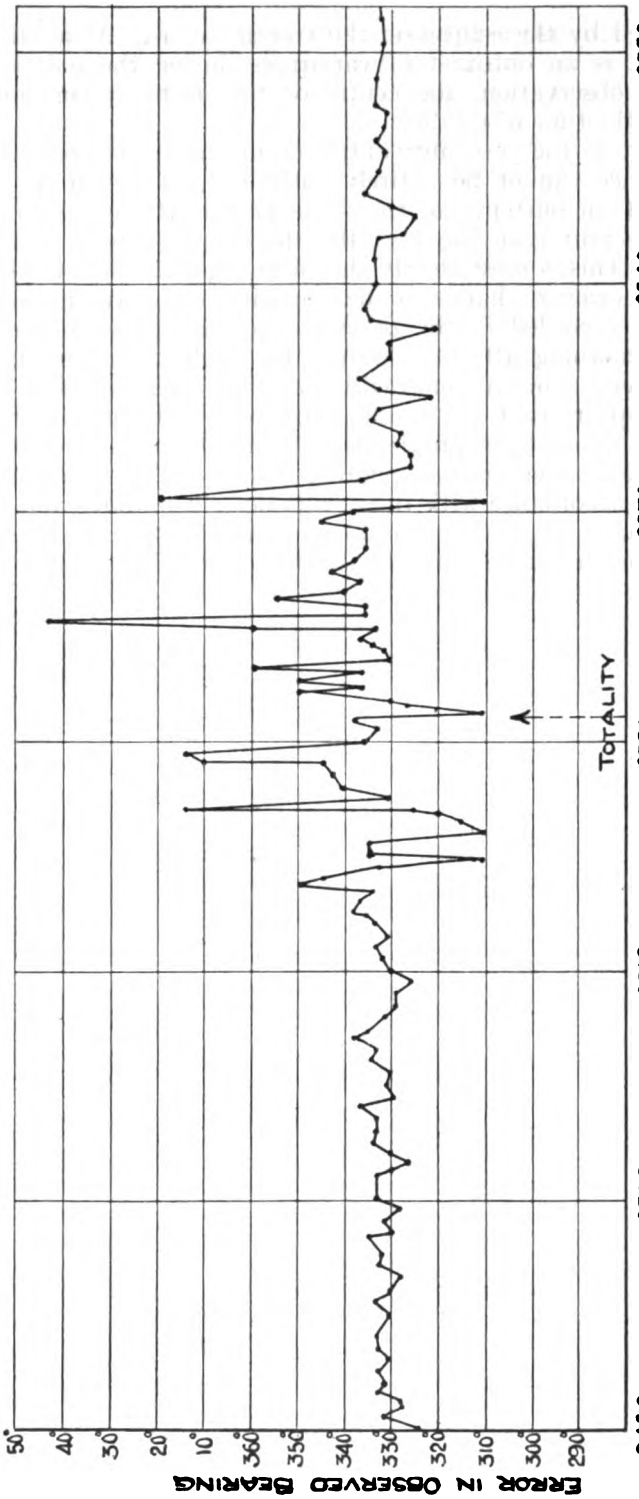

FIG. 15.—*Enlargement of the graph in Fig.* 14 *for the period of the eclipse only, June 29th, 1927.*

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effect produced by the eclipse on the transmissions. At all these stations there is an outburst of variations during the half hour of maximum observation, the centre of the outburst coinciding roughly with the time of totality.

Unfortunately the possibility of this occurrence being somewhat of a coincidence cannot be entirely ruled out, as shown by the appearance of an outburst of the same nature (though certainly not quite so definite), on the day after the eclipse—about half an hour earlier. This is most clearly shown in Figs. 12 and 14. It is to be noted, however, that in connexion with the wave intensity measurements recorded in the previous section, it was observed that on the morning after the eclipse the night-time conditions appeared to persist for an abnormally long time after sunrise.

It thus appears that the results show a definite indication of an effect due to the eclipse, proving that the normal night properties of the Heaviside layer were temporarily restored. This conclusion is in complete accordance with the results described above and the directional variations may be ascribed to the observed changes in the effective height and reflection coefficient of the ionised layer.

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Observations on the Variations in the Strength of Signals received at Liverpool University from Stavanger (Norway) by Professor E. W. Marchant and Mr. E. Youel

It was arranged for special signals to be transmitted from Stavanger (Norway) and to be received and measured in Liverpool

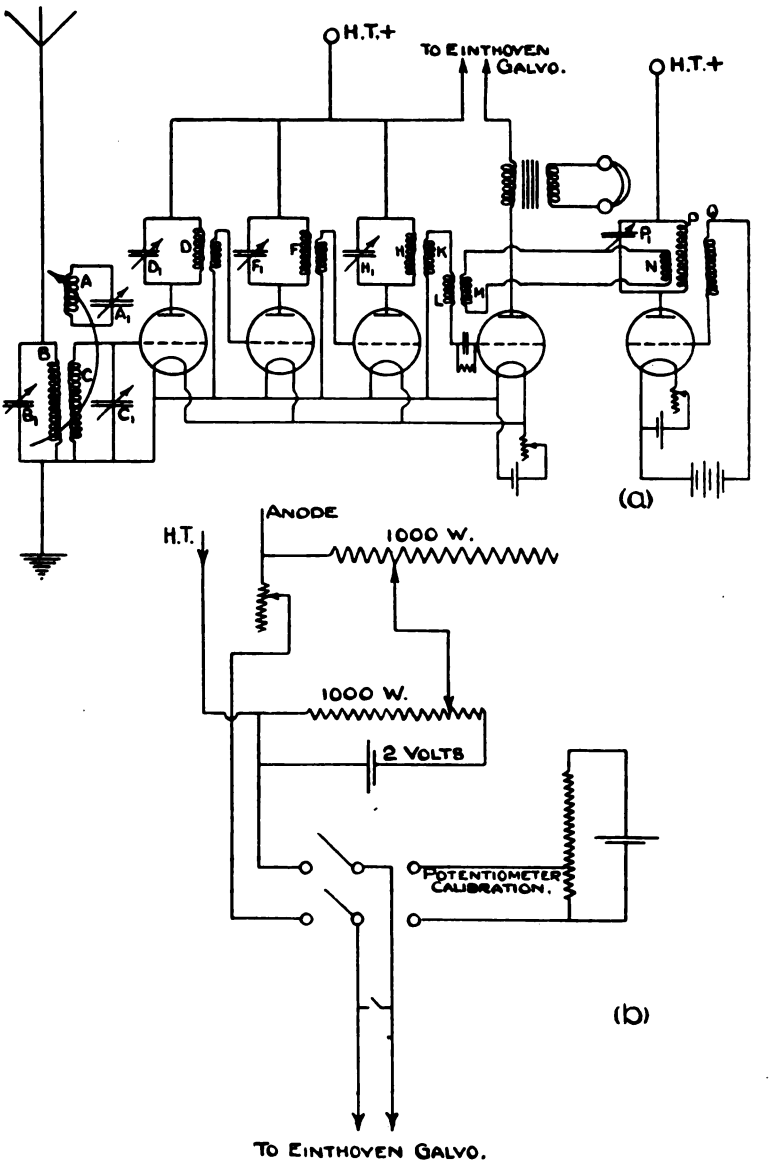

FIG. 16.—*Circuit arrangement employed at Liverpool for the signal intensity measurements of the transmissions from Stavanger.*

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during the time of the eclipse. These signals took the form of a number of dashes of two seconds' duration spaced by intervals of two seconds, to be followed at regular intervals by a succession of V's and the call sign L.C.M. of the station. They were transmitted from 0500 to 0600 between 27th June and 1st July inclusive, with an extension to 0700 on 29th June.

The circuit used for receiving the signals is shown diagrammatically in Fig. 16 (*a*). A special receiving circuit was built, care being taken to keep the components well spaced. It consisted of three high frequency amplifying valves, one rectifier and one heterodyne oscillator. The circuit A was used as a wave trap for absorbing any interfering stations. The detector valve grid circuit was loosely coupled to a heterodyne oscillator by means of coils L, M and N. Tuning was carried out by means of a standard Sullivan wavemeter. An Einthoven galvanometer was used for measuring the anode current from the detector valve.

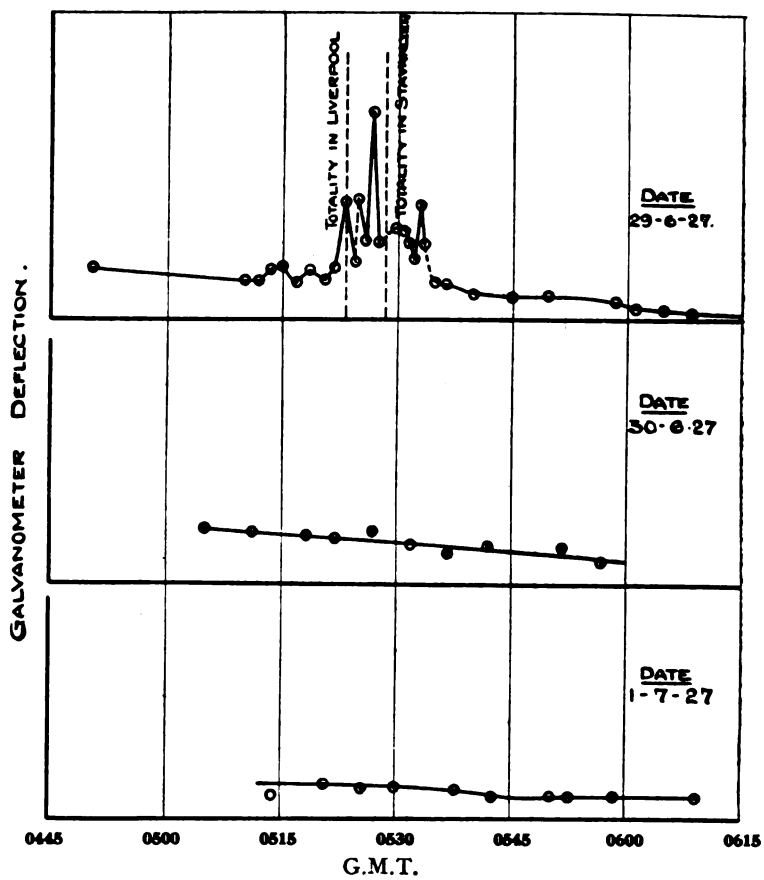

FIG. 17.—*Graphs showing the signal current received at Liverpool from Stavanger on June 29th and 30th and July 1st, 1927.*

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In order to prevent the steady anode current of the detector valve from passing through the galvanometer a balancing circuit was used, balance being roughly adjusted by means of a unipivot galvanometer whilst the Einthoven galvanometer was short circuited. The balancing circuit is shown in Fig. 16 (*b*). The calibration of the Einthoven galvanometer was checked before and after each reading, when possible.

No signals were measured on 27th and 28th June, but the period was spent in making final adjustments to the receiver and in getting the station accurately tuned in. All night readings were taken from 2215 on 28th June until 0700 on 29th June. Records were taken as rapidly as possible during the eclipse, the strength of signal received being measured on a photographic plate.

Fig. 17 shows the records obtained for the day of the eclipse and for the two following days.

The results show a definite peak in the curve of signal strength during totality in Liverpool and one of greater magnitude when there is totality approximately half way between Liverpool and Stavanger. These results are approximately the same as those observed at sunset and sunrise and show that the effect produced by sunlight on the ionisation of the atmosphere must occur quite rapidly. The variation in signal strength may be regarded as being due to the variation in position of the Heaviside layer, and these results therefore confirm the view that there are rapid changes in the state of ionisation of this layer. The maximum strength of signal observed during totality in Liverpool was very nearly the same as the normal night signal, but the signal strength observed when the shadow was about midway between Liverpool and Stavanger was about twice as great as the normal night signal. The existence of a series of peaks in the curve of signal strength variation may be explained by the assumption that the signal received at Liverpool from Stavanger is due to a combination of an almost direct wave and a wave reflected from the Heaviside layer, the variation in signal strength being due to the variation in the relative phases of the two waves.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

RADIO RESEARCH

SPECIAL REPORT No. 8

AN INVESTIGATION OF THE INTERFERENCE CAUSED BY TRANSMISSIONS FROM RADIO STATIONS

PART I. THE MEASUREMENT OF THE EQUIVALENT DECREMENT OF VARIOUS TYPES OF RADIO TRANSMISSIONS

BY

R. L. SMITH-ROSE, D.Sc., Ph.D., A.M.I.E.E., AND F. M. COLEBROOK, B.Sc., D.I.C., A.C.G.I.

PART II. THE STUDY OF THE INTERFERING PROPERTIES OF RADIO TRANSMISSIONS

BY

F. M. COLEBROOK, B.Sc., D.I.C., A.C.G.I.

LONDON: PUBLISHED UNDER THE AUTHORITY OF HIS MAJESTY'S STATIONERY OFFICE, 1929

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INTRODUCTORY NOTE

THIS Report describes an investigation commenced in April, 1923, under the direction of the Radio Research Board in response to a request from the Sub-Committee on Technical Wireless Regulations of the Imperial Communications Committee. This Sub-Committee, being engaged in drafting national wireless regulations which might form the basis of proposals for the 1927 meeting of the International Radio Telegraph Convention, asked the Board to consider the utility of certain figures for " equivalent decrement " as a basis for the classification of transmitting stations in respect of their interfering properties ; " equivalent decrement " being a quantity defined in Section LXXXII of the Regulations of the Washington Draft Convention of 1920, and described more fully in Part I of the Report.

From the results of experimental measurements carried out by the National Physical Laboratory during the years 1923–24 it was concluded that the quantity " equivalent decrement " was not an adequate criterion of interference in radio communication. Some experiments were also made by Mr. F. E. Nancarrow, of the Post Office Engineering Department, which confirmed this conclusion. At this stage the Sub-Committee on Technical Wireless Regulations set up a special Sub-Committee on Interference with instructions to report on the subject of equivalent decrement and, if necessary or desirable, to present alternative proposals. On the basis of further experimental work by the National Physical Laboratory during 1925 this Sub-Committee confirmed the inadequacy of " equivalent decrement " and put forward alternative proposals based on the energy spectrum of the transmission. As it was apparent that considerable research on this subject would be necessary before any practically realisable specification of interfering effect could be formulated, the above Sub-Committee was

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absorbed into a special Committee set up by the Radio Research Board in 1926 to conduct this research.

During the years 1926–28 a considerable amount of theoretical and experimental work was carried out at the National Physical Laboratory, but this had failed to produce a practical and easily applied method of measuring interference. In the meantime, owing to various improvements in the technique of radio communication, the necessity for immediate legislation on the subject had decreased. Furthermore, largely as the result of the work carried out in this country and described in the present Report, the International Radio Telegraph Convention held at Washington in 1927 abandoned the use of the quantity " equivalent decrement " and made no alternative suggestion for defining interference. It was decided, therefore, to discontinue this rather unpromising line of research. In view, however, of the probable importance of the problem of interference in connexion with the future regulation of radio communications, it has been considered desirable to draw up the accompanying Report as a record of the progress made and a statement of the difficulties to be overcome.

E. H. SHAUGHNESSY,
Chairman of the Interference Committee.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH,

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AN INVESTIGATION OF THE INTERFERENCE CAUSED BY TRANSMISSIONS FROM RADIO STATIONS

PART I. THE MEASUREMENT OF THE EQUIVALENT DECREMENT OF VARIOUS TYPES OF RADIO TRANSMISSIONS

1. Proposed Classification of Radio Transmitting Stations and the Definition of "Equivalent Decrement"

In Section LXXXII of the Regulations of the Washington Draft Convention of 1920 it was proposed to classify radio transmitting stations in accordance with the type of waves they emit rather than in accordance with the type of apparatus used for producing the waves. The proposed classification of waves was as follows:—

Type A.—Continuous Waves.—Waves arising from oscillations which, after reaching the steady state, are periodic, i.e., the successive oscillations are identical.

Type A1.—Continuous Waves, key modulated.—Continuous waves of which the amplitude or frequency is varied by the operation of keying in telegraphic transmission.

Type A2.—Continuous waves modulated by audible frequency.—Continuous waves in which the amplitude or frequency is varied in a periodic manner at an audible frequency.

Type A3.—Continuous waves modulated by speech.—Continuous waves in which the amplitude or frequency is varied according to the characteristic vibrations of speech.

Type B.—Damped waves.—Waves consisting of successive wave trains in which the amplitude of the oscillations, after reaching its maximum, declines gradually.

These definitions do not refer to types of transmitting apparatus. They do not exclude, for example, from type A1 emissions from spark apparatus which produce real continuous waves. Within each of the above types it was proposed to classify the waves according to the degree of interference they produce in communication work, making use for this purpose of a quantity termed "equivalent decrement," which is derived in the following manner.

The resonance curve of the root-mean-square value of the current (I) in a receiving circuit is determined with respect to the

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TABLE 1.—*Proposed limiting values of equivalent decrement to be allocated to the various types of transmissions on different wave lengths*

Wave.		Type and Decrement.			
Frequency.	Length.	A1.	A2.	A3.	B.
∞ –300 kc./s. ..	0–1,000 m. ..	0·000 to 0·005	0·005 to 0·02	0·02 to 0·08	0·08 to 0·16
300 –105·3 kc./s. ..	1,000–2,850 m. ..	0·000 to 0·005	0·005 to 0·02	0·02 to 0·08	0·08 to 0·16
105·3– 37·5 kc./s. ..	2,850–8,000 m. ..	0·000 to 0·005 (hand) .. 0·005 to 0·02 (auto) ..	0·02 to 0·08	0·08 to 0·16	0·08 to 0·16
37·5– 0 kc./s. ..	8,000– ∞ m. ..	0·005 to 0·02	—	—	—

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natural frequency (f) of the circuit. The quantity δ defined by the equation :—

$$\delta = \pi \frac{f_1 - f_2}{f_r} \sqrt{\frac{I^2}{I_r^2 - I^2}}$$

is then determined from the resonance curve ; f_1 and f_2 being the two frequencies on either side of f_r (the frequency of the transmission) at which I is measured, it being conditionally accepted that the frequencies be selected over the range between the limits $0{\cdot}9 f_r$ and $1{\cdot}1 f_r$ and that I^2 shall not exceed $\frac{1}{2}I_r^2$. If the quantity so determined is found to vary with f, the largest value obtained should be taken. A repetition of the above measurement with a continuous wave source of sine wave radiation of the same frequency will give the value of δ for the receiving circuit. The difference between the two values of δ is then described as the " equivalent decrement " of the given transmission. On the basis of this definition the preceding table (Table 1) of permissible decrements for the various types of transmission mentioned above was formulated provisionally, and it was with the object of ascertaining the practical utility of the figures in this table that the first experiments were undertaken in 1924.

2. Methods of Measuring Equivalent Decrement

In a paper read before the Institution of Electrical Engineers in 1922, Erskine-Murray and Williams[1]* described an experimental method of measuring the decrement of the waves transmitted from a distant spark station. Using a frame coil receiver, the combined decrement of the transmission and the receiver was measured by observing the change in the capacity of the condenser required to detune the receiver by an amount sufficient to reduce the received current to $\frac{1}{\sqrt{2}}$ of its maximum value in the condition of circuit resonance. The received currents were not measured directly, but the ratio $\frac{1}{\sqrt{2}}$ was obtained by comparison with the current received on the tuned coil first, when it was set in the maximum position and secondly, when rotated through 45° from this position. The current was indicated either by a crystal detector and galvanometer coupled to the last audio-frequency stage of the receiver, or by the use of a thermionic voltmeter. In the discussion on this paper it was pointed out by Round that such instruments do not necessarily read R.M.S. values of current or voltage for damped oscillations, and that since in the two sets of measurements the receiving loop is respectively tuned and distuned, it must not be assumed that the envelope of the wave-form of the received current

* These numbers refer to the bibliography on page 40.

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is the same in the two cases. It is thus doubtful if equality of rectified signal current in the two observations implies equality of the R.M.S. values of these currents, and the corresponding error would vary with the wave-damping and type of transmission and is, in any case, unknown. The decrement of the receiving circuit was measured by Erskine-Murray and Williams by separate measurement of its constants with the aid of a local source of continuous oscillations, all conditions being maintained as far as possible identical with those in the previous measurements. The only decrement value given in the paper refers to observations on the damped wave " spark " transmissions from Paris, the value obtained on a wave-length of 2,600 metres being 0·16. It is not stated if this referred to a steady dash or to the transmission of Morse signals.

For the determination of the equivalent decrement of a transmission as defined in the previous section, it is clear that the principal requirement is an instrument capable of measuring small radio-frequency currents in the receiving circuit, or of the small radio-frequency potentials of the order of from 0·001 to 0·1 volts which result across the tuning condensers of such a circuit. The instrument should not add substantially to the decrement of the circuit to which it is attached, its calibration must remain reasonably constant, and by no means least important, the indications of the instrument must follow a square law over its whole working range so that it will read the mean square value of a current of any wave form. With the advance in the technique of radio-frequency measurements it is evident that the valve voltmeter in one or other of its several forms meets the above requirements, and it was with an early pattern of such an instrument that measurements of equivalent decrement were begun at the National Physical Laboratory in 1923. From the commencement, it was considered desirable to plot complete resonance response curves in these measurements rather than to limit the observations to specified current values. To obtain the necessary scale range for this purpose, combined with the square-law condition, necessitated the use of a fairly sensitive reflecting galvanometer to indicate the change in anode current of the valve. By means of this type of instrument a reading proportional to the square of the voltage induced in a receiving circuit by the station being measured can be obtained. A curve showing variation of this reading with a suitable variation of the tuning condenser on either side of resonance can be plotted. A similar curve can be obtained for a local continuous wave source of the same wave-length or for continuous waves transmitted from the same station. Finally, the receiving circuit can be calibrated for wave-length over the range of tuning condenser employed in the first two curves, by means of a local oscillator or wave meter. These three curves will give all the information required for the determination of the equivalent decrement of the transmission.

The type of receiving circuit used varied with the conditions of measurement. Thus the stations at Leafield, Northolt and Ongar

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gave ample signal strength on a 100-foot aerial with parallel condenser tuning, but unless specially arranged transmissions were sent from these stations for the purpose of the measurement, the aerial could not be used owing to the impossibility of obtaining the C.W. and wave-length calibrations, since the stations worked almost continuously. The readings for these stations were, therefore, taken on a frame receiving coil which could be set in the position of zero reception for the purpose of calibration on the local oscillator. It was found necessary to use a radio-frequency amplifier in conjunction with the frame to make the received signals large enough for measurement.

Apart from this difficulty of the local oscillator calibration, however, the use of the aerial and the direct measurement of the signal e.m.fs. are to be preferred. A special advantage of the latter is that by inserting a suitable coil in the anode circuit of the measuring valve and coupling this to the aerial tuning inductance, the decrement of the whole receiving circuit can be reduced to as low a figure as 0·002 without any instability.

In the case of some later measurements made on the transmissions from the North Foreland " spark " station it was necessary to employ portable apparatus, and the limitations of such apparatus are referred to later.

3. Results of Measurement of Equivalent Decrement

(*a*) *Experiments made at the National Physical Laboratory*

With the aid of the apparatus described above a number of measurements were carried out at the National Physical Laboratory on various types of wireless transmissions. For the most part normal commercial transmissions were made use of for this purpose but a local transmitter at the Laboratory was also employed. A summary of the results obtained is given in the following Table 2.

Table 2.—*Summary of results of measurements of equivalent decrement made in* 1924 *at the National Physical Laboratory on various types of transmissions*

Station and Wave-length.	Type of Transmission.	Equivalent Decrement.	Permissible Equivalent Decrement proposed in Section LXXXII.
Northolt (GKB), 6,950 metres	Keyed C.W., hand speed; two wave-lengths	0·003	0·000–0·005
Ongar (GLB), 3,840 metres	High speed. Automatic C.W.	Less than 0·001	0·005–0·02

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TABLE 2—*continued*

Station and Wave-length.	Type of Transmission.	Equivalent Decrement.	Permissible Equivalent Decrement proposed in Section LXXXII.
Leafield (GBL), 8,570 metres	Keyed C.W., hand speed ; two wave-lengths (8,528 and 8,612 metres)	0·011 to 0·024, depending on the ratio of I^2 to I^2_r	0·005–0·02
N.P.L. (5HW), 762 metres	Spark—		
	Long dash ..	0·05	0·08 to 0·16
	Dots at hand speed	0·05	0·08 to 0·16
N.P.L. (5HW), 762 metres	Interrupted C.W.	0·006	0·005–0·02
London (2LO), 365 metres	C.W. Modulated by speech and music	Less than 0·001	0·02–0·08
Chelmsford (5XX), 1,600 metres	C.W. Modulated by speech and music	Less than 0·001	0·02–0·08

In the case of telegraphic working the use of the normal commercial transmission of the station is not very suitable for accurate measurement since the galvanometer deflections show rapid fluctuations due to variations of mean intensity caused by the Morse keying. The readings recorded were mean values. By measurements made on a special transmission from the Laboratory station (5HW) it was found that a regular train of dots at hand speed gave a constant deflection, and it will be noticed that the equivalent decrement measured in this manner agreed with the value obtained on a steady dash on the spark transmitter. The actual curves obtained in this latter case are shown in Fig. 1. In the case of the observations made on the arc transmissions from Leafield (GBL) measurements were obtained on Morse signalling and on both the continuous marking and the continuous spacing wave, as shown in Figs. 2 and 3. For a curve of the type shown in Fig. 2 the equivalent decrement measured as defined above is not constant but appears to increase with I_1^2/I_2^2 up to $I_1^2 = \frac{1}{2}I_2^2$.

(b) Experiments made at the North Foreland Station

With a view to obtaining further information on the application of equivalent decrement to spark transmitters, some measurements were carried out on the transmissions from the Post Office "spark" station at North Foreland (GNF) in December, 1925.

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Some preliminary observations carried out on these transmissions showed that, owing to the comparatively low power of the station and the interference from other stations on the same

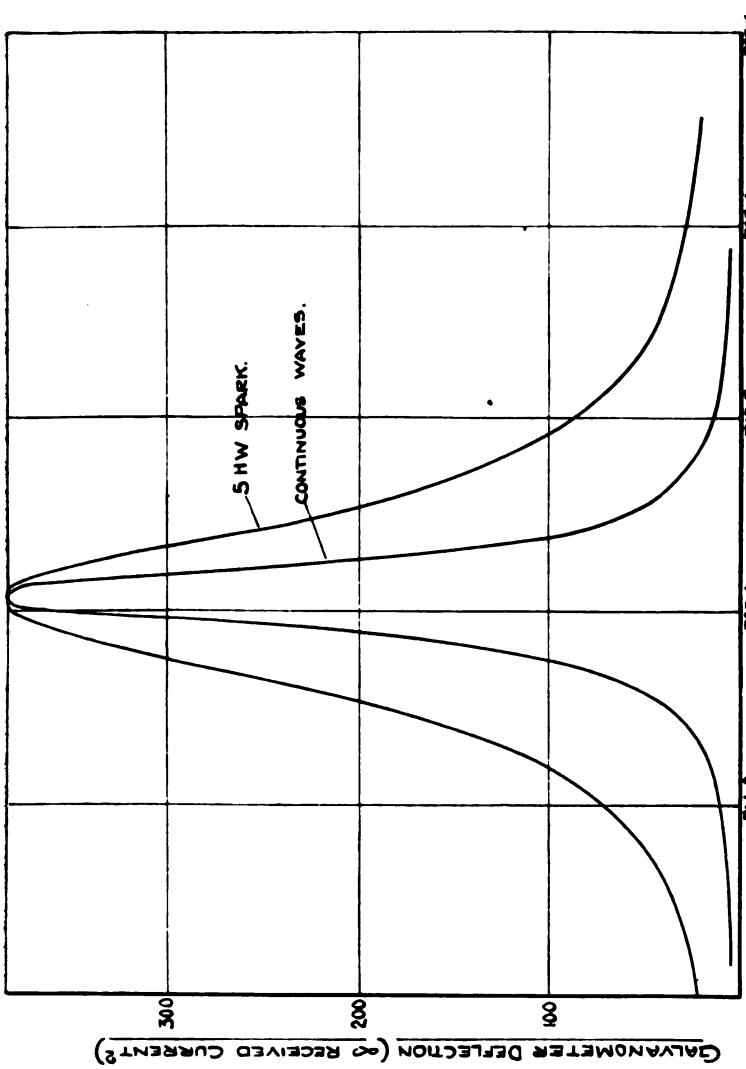

FIG. 1.—*Resonance curves showing current in a receiving circuit for a steady dash from a spark transmitter at the National Physical Laboratory and from a local source of continuous waves.*

wave-length, it was impracticable to make any accurate measurements at Teddington, about 90 miles distant. It was, therefore, decided to modify the apparatus previously employed so as to make it fairly portable, and then to use it within a comparatively short distance of the transmitter.

A frame coil, 2 feet square, was employed with suitable tuning condensers, and the potential difference across these was measured

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with a simple rectifying valve arrangement with the steady anode current balanced out. On account of portability it was necessary to use a pointer galvanometer; and it was found that the most sensitive of these suitable for the purpose did not permit of the

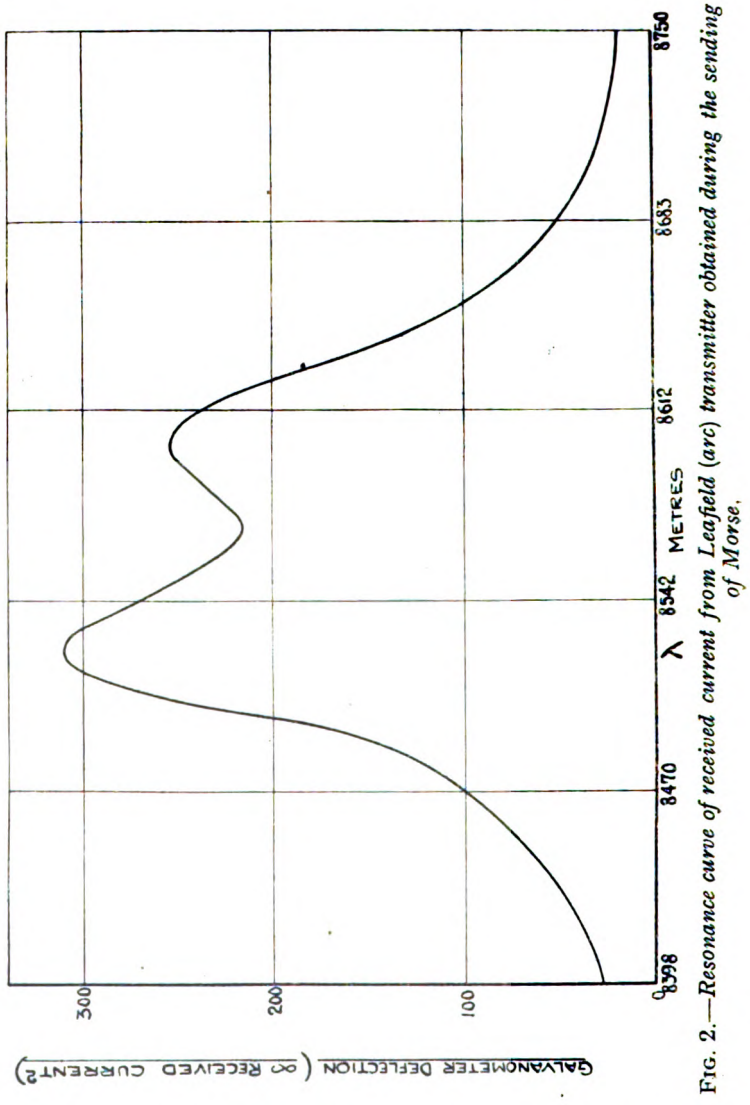

FIG. 2.—*Resonance curve of received current from Leafield (arc) transmitter obtained during the sending of Morse.*

valve being worked within the range over which the change in anode current of the rectifying valve was proportional to the square of the voltage applied to the grid. This meant that the instrument would not read true R.M.S. values for trains of damped waves. It was found that the response of the instrument was such as to

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make the resonance curve steeper than it should be, corresponding to a lower value of equivalent decrement, but in view of the urgency of forming some definite opinion as to the utility of the quantity "equivalent decrement," it was considered expedient to make the approximate measurements possible with the apparatus.

The measurements were made in the lighthouse at North Foreland, the distance from the frame to the nearest point of the aerial being about 100 yards. At this distance the resonant potential

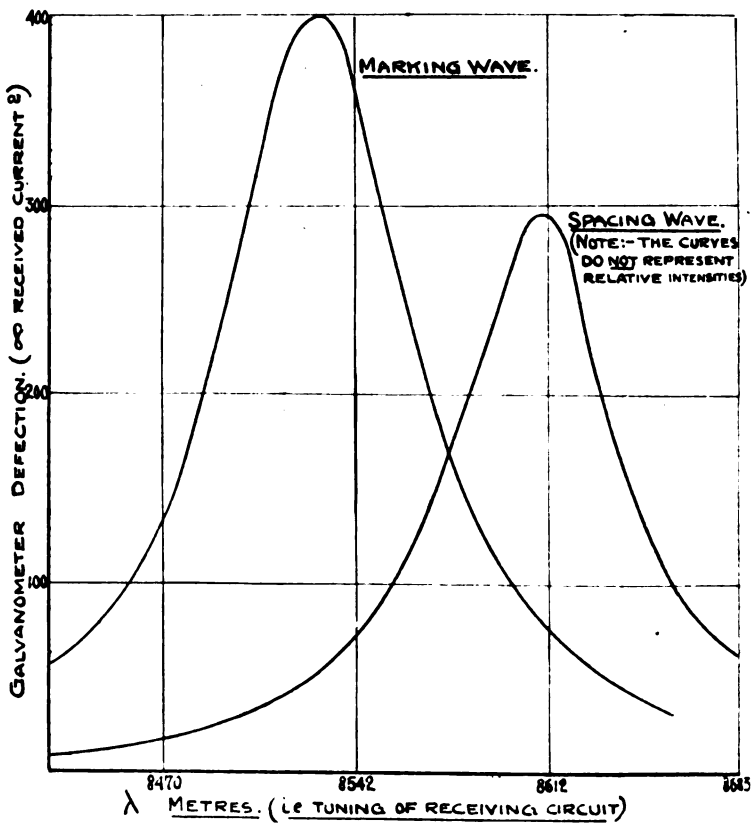

FIG. 3.—*Resonance curves of received current from Leafield for a steady dash on both marking and spacing waves.*

difference across the frame terminals was over 4 volts. As full scale deflection on the galvanometer was obtained for about 1·2 volts, this made it possible to measure the peak of the resonance curve with the frame turned out of the maximum position, and so increase the relative sensitivity of the instrument for the lower portions of the curve.

It is realised that at such a short distance from the transmitter the effective wave-form of the radiation may be somewhat modified

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by the presence of the induction field of the aerial. This again is a somewhat obscure point that must be left for future investigation ; but it is anticipated that the error introduced by neglecting the induction field will not be serious. A careful test carried out with the aerial disconnected showed that there was no detectable field from the primary or intermediate circuits of the transmitter.

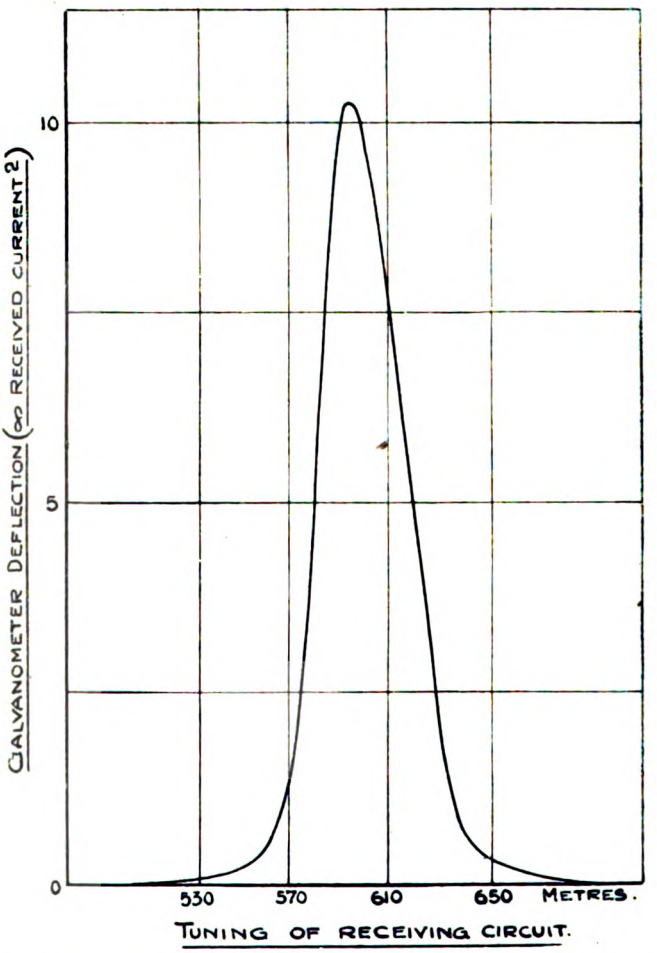

FIG. 4.—*Resonance curve of received current from North Foreland (spark) transmitter taken on a local loop receiver.*

The resonance curve of the receiving circuit when using a continuous wave source showed that the decrement of the receiving coil was fairly low, its actual value being 0·018. On the North Foreland station, the resonance curve obtained with the intermediate circuit in position, as normally used at that time, is shown in Fig. 4. It is at once evident that the transmission shows a

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serious equivalent decrement, its calculated value being 0·24. On either side of this main peak on 600 metres, the curve falls to the zero line but, by careful search, a second peak was discovered on a wave-length of about 760 metres, the height expressed as the square of the voltage of this small peak being about 0·0034 of that of the main peak. Although repeated search was made, no signal voltage could be detected in either this or any of the other tests, on wave-lengths corresponding to the second and third harmonics.

With a view to obtaining some further information about this second peak, the couplings between the primary and secondary, and between the secondary and aerial circuits of the transmitter were reduced slightly, such retuning as was necessary being made to bring the aerial current back to a maximum. By repeating the measurement of the resonance curve, it was found that the small peak had increased considerably in amplitude and that it now occurred at a shorter wave-length. After a second reduction of both couplings as above, the curve shown in Fig. 5 was obtained, with the peaks occurring at still closer wave-lengths. It would appear from these experiments that the existence of the second peak was due to the coupling of the circuits being too close, and that if this could be sufficiently reduced and a means of tuning each of the three circuits could be found, the two peaks could be merged into one. It is to be observed that the reduction of the couplings resulted in a slight increase in aerial current from 6·0 to 6·5 ampères under stable conditions of working. The calculated equivalent decrement from the curve in Fig. 5 vary from 0·09 to 0·17 depending upon the portion of the curve chosen for the calculation, the highest values being obtained at a part of the curve which embraces the second peak. It is evident that this value takes no account of the height of this second peak, and thus is not, therefore, a measure of the amount of interference caused by it.

Similar measurements were carried out with the intermediate circuit at the transmitter removed, and it was found that, while two peaks were obtained when the coupling was close, these could easily be reduced to one without serious reduction of the aerial current. In this latter condition the equivalent decrement of the transmission was found to have a mean value of 0·17. Since the merging of the two peaks into one by reduction of the coupling did not materially increase the equivalent decrement of the main peak, it is to be expected that if, with the intermediate circuit in place, the couplings could be reduced below the values used for Fig. 5, a value of the equivalent decrement of the order of 0·1 could be obtained. It would, furthermore, appear that it is only in this condition that the use of the intermediate circuit would be of any material advantage in reducing the interfering properties of the transmitter.

As was pointed out above, the inherent error of the valve voltmeter as used in these tests would have the effect of reducing the

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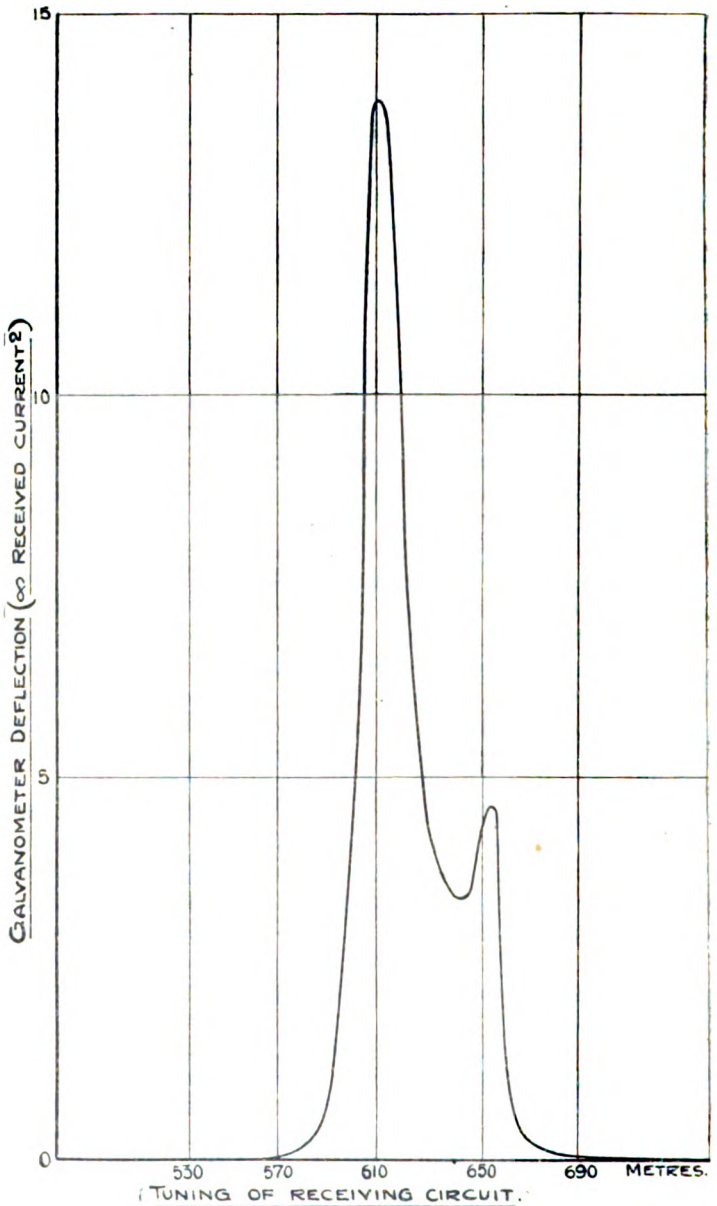

FIG. 5.—*Measurements in Figure 4 repeated with* ***closer coupling*** *of the circuits in the transmitter.*

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equivalent decrement values obtained. These are therefore to be considered as minimum values for the transmitter. In view of this fact, it is interesting to recall that the equivalent decrement given by the spark transmitter, as installed and measured at Teddington in 1924, was 0·05 (see section 3 (*a*) above). It is also to be recalled that, as stated in Table 1, the proposed permissible range of equivalent decrement for this type of transmission was 0·08 to 0·16.

4. Discussion of above Measurements and Conclusions to be drawn therefrom

From the experimental results given in the last section it will be seen that, in the case of the transmissions from arc and spark stations, the measured values of equivalent decrement are in fairly good agreement with the values originally proposed and detailed in Table 1. In the case of the spark transmissions, while the allocation of an equivalent decrement value may thus prove to be a minimum condition to be satisfied, it is considered to be inadequate for the following reasons, which were brought to light by the experiments carried out at North Foreland.

(*a*) The definition of equivalent decrement takes no account of possible additional peaks in a resonance curve on wavelengths differing by more than 10 per cent. from that of the principal peak ; although any such peaks, whether due to harmonics or to coupling conditions, might cause serious interference.

(*b*) In the event of the resonance curve showing two or more peaks in close proximity, then the highest decrement value, obtained from the lower part of the curve covered by both peaks, will not necessarily take account of the height of the subsidiary peak, although this would obviously affect the interference caused by the transmission.

In the case of continuous wave transmitting stations, the results quoted in the last section showed that there is no appreciable equivalent decrement arising from the modulation by telephony or Morse keying, except where Morse signalling is effected by a key controlled change in frequency. This, however, is quite inconsistent with actual experience of interference, for it is found that high speed telegraphy by key controlled amplitude modulation of single frequency waves will give rise to " key-click " interference in circuits tuned to neighbouring frequencies, which interference is generally considered to be more serious than that due to frequency change keying. The appreciable equivalent decrement associated with the latter system is, therefore, misleading as a means of rating its interfering effects.

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Further, it is a fact of experience that the degree of interference caused by medium wave-length telephony transmissions (e.g., 5XX), particularly in the case of telephone reception on frequencies differing by 10,000 cycles or less from that of the interfering station, is considerably greater than that which would be inferred from the very low equivalent decrement of such transmissions.

It is, therefore, to be concluded that equivalent decrement measurements will not serve as an equitable or effective check on C.W. transmissions, keyed, interrupted or modulated, for the following reasons :—

(*a*) Measurements have shown that the keying of single wave-length C.W. stations produces no appreciable effect on the resonance curve, but it is a fact of experience that it does give rise to interference on neighbouring wave-lengths.

(*b*) Stations of which the keying changes the wave-length would have an equivalent decrement larger than is actually representative of the interference caused by such transmissions.

(*c*) In the case of telephone transmissions in which the modulation percentage is small the measured equivalent decrement is practically zero, since the modulation only very slightly affects the root-mean-square value of the received current. This quantity cannot, therefore, represent the interfering properties of such transmissions.

(*d*) Finally, with all the above types of transmissions the equivalent decrement definition entirely ignores all the harmonics of the transmission, and these harmonics are known in some instances to be the most serious factor of the interference produced by the transmitter.

While it is to be concluded from the above considerations that as a general and adequate criterion of interference the quantity " equivalent decrement " is unsuitable, it has been suggested that it might possbly form a useful minimum condition for the basis of regulations on interference from spark stations, provided the restriction as to the $\frac{1}{2}I^2$ value were removed and provided that a further regulation restricted the emission outside the $\pm$ 10 per cent. band to some specified intensity.

5. Possible Alternative Telephonic Methods of Measuring Interference

The failure of the method described in Section 2 to discriminate between continuous oscillations on the one hand and either high-speed Morse transmission or telephony on the other, indicates that the interference experienced in practical communication is due to transient currents or currents of a kind that will not be recorded by

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a root-mean-square measuring instrument of the type contemplated in the equivalent decrement definition. This can be illustrated very simply in the case of a pure tone modulated carrier wave. Suppose the current be of the type

$$i = \hat{\imath}\ (1 + k \sin mt) \sin \omega t$$

$\omega/2\pi$ being a radio frequency, $m/2\pi$ an audible frequency, and k the modulation percentage. The square of this current is

$$i^2 = \frac{\hat{\imath}^2}{2}\left(1 + \frac{k^2}{2}\right) + \frac{\hat{\imath}^2}{2}\left(2k \sin mt - \frac{k^2}{2} \cos 2mt\right)$$
$$- \frac{\hat{\imath}^2}{2}\left(1 + \frac{k^2}{2} + 2k \sin mt - \frac{k^2}{2} \cos 2mt\right) \cos 2\omega t.$$

Of the terms on the right-hand side, the first group is a continuous current, and is *the only one which would be recorded by a root-mean-square measuring instrument.* In fact

$$\text{Mean value of } i^2 = \frac{\hat{\imath}^2}{2}\left(1 + \frac{k^2}{2}\right) = \mathrm{I}^2\left(1 + \frac{k^2}{2}\right).$$

The second group would not affect the measuring instrument but, being audible frequency currents, would obviously give rise to interference in telephone reception. The third group, consisting of radio frequency currents, would not affect the measuring instrument and would not cause interference in telephone reception.

Note further that if k is 0, the mean value of i^2 is I^2, which is less than before by the factor $\left(1 + \frac{k^2}{2}\right)$. Thus if k is 30 per cent. the mean value of i^2 is only increased by $4\frac{1}{2}$ per cent. by the modulation, which small variation is certainly no measure of the interference produced by the low frequency group of currents (which are proportional to k).

It is not suggested that this is an exact representation of an interference effect, but it serves to show that interference may and probably will arise from factors of which the equivalent decrement root-mean-square measurements do not take proper account.

In view of the above it was considered that some telephone audibility method might be more effective in estimating interference. In one of the methods investigated with this object in view, two screened variable mutual inductances were employed, either of which could be connected in turn between the aerial or frame coil and the receiver by the operation of a change-over switch. These inductances were identical in design and construction so that when they were both tuned and set at equal couplings, equal signals would be obtained in both positions of the change-over switch. By detuning the circuits connected to one of the mutual inductances the strength of signal received in the telephone is reduced, and this can be balanced against the signal received in the other positions of the switch with its corresponding circuits still

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tuned but with the couplings decreased by a suitable amount. Proceeding in this manner the decrease in signal strength produced by distuning one circuit could be measured by the diminution of coupling in the other circuit.

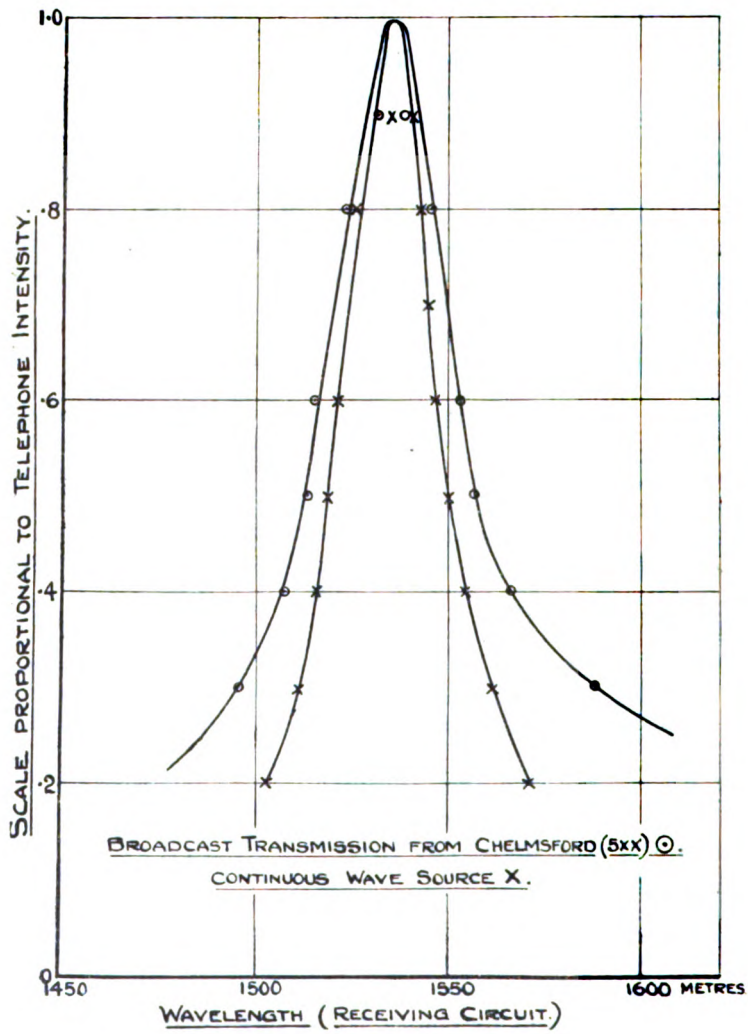

FIG. 6.—*Resonance curves illustrating the interfering effect of a transmission from Chelmsford (5XX) as measured by an audibility method.*

As an alternative to the use of variable mutual inductances, the two receiving circuits could be connected up through an audio-frequency amplifier giving a known voltage amplification variable over the range of 1 to 100.

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Both the above methods have been set up and tested in the experimental stage. In the case of high-speed Morse and of broadcasting transmission on a wave-length of 360 metres, no increase in the effective decrement could be observed over that obtainable on continuous waves. Some measurements made on the longer wave broadcast transmission from Chelmsford, however, did show a definite difference between the interfering effect of this station and that of a pure continuous wave, the results being illustrated by the typical curves given in Fig. 6. It was also observed that the detuning of the receiving circuit produced a very marked difference in the quality of the telephony which considerably increased the difficulty of establishing a telephone balance. This rather serious limitation combined with the somewhat low accuracy always associated with telephone audibility measurements, led to the suspension of these experiments while other methods of attacking the problem were being investigated. A description of these methods is embodied in Part II of this Report which deals with the further investigation of the whole problem of interference from wireless transmissions from a more general point of view.

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PART II. THE STUDY OF THE INTERFERING PROPERTIES OF RADIO TRANSMISSIONS

6. Proposals for a Criterion of the Interfering Capability of a Transmission

It has been shown in the preceding sections that "equivalent decrement" cannot be regarded as a satisfactory measure of the interfering capability of a wireless signal transmission. It now remains to outline proposals for a theoretically valid measure of interfering capability.

Any wireless transmission is the controlled radiation of energy through space, and the element of control which is essential for signalling purposes makes it impossible to restrict the energy radiated to a single frequency. In fact the only possible single frequency radiation is one of pure sine wave form of which the period and amplitude are constant, i.e., $\hat{e} \sin \omega t$ where t extends from $-\infty$ to $+\infty$. This, even if realisable, would be useless for signalling purposes. As distinct from this, any radiation which can be used for signalling purposes will of necessity have an imperfectly periodic character with a controlled variation of amplitude or frequency or both. It is a matter of common knowledge that such a disturbance is associated with a continuous distribution of energy with frequency (see Appendix 1). Theoretically the distribution will extend over the whole range of frequencies between zero and infinity cycles per second. In practice, however, the bulk of the energy carried by such a radiation will be associated with a bounded frequency zone in the neighbourhood of the principal frequency of the transmission.

The extent to which such a transmission will produce an undesired response in a circuit intended to receive some other transmission will obviously depend on the selectivity of the receiving circuit (i.e., its frequency-response characteristic) and on the energy-frequency characteristic of the transmission. It appears, therefore, that the energy-frequency or power-frequency characteristic of a transmission is the natural basis for any criterion of its interfering capability.

As an example of the energy distribution of the type of radiation involved in wireless signalling consider a 1,000 KW. station which transmits a single Morse dot at a nominal frequency of 15,000 cycles per second at, say, a speed corresponding to 55 words per second (i.e., about 250 complete oscillations to a dot). For simplicity neglect the initial and final transient states of the transmitting system and assume that the radiated field at some given point can be represented by $e = \hat{e} \sin 30{,}000\pi t$, for all values of t from $t = 0$ to $t = 1/60$ second, and $e = 0$ for all other values of t. Fig. 7 shows the spread of the energy of a disturbance of this type over the spectrum in the neighbourhood of the mean frequency. (The

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figure actually corresponds to fifty complete oscillations which gives a more pronounced spread and is, therefore, better for illustration.) It can be shown that the ordinates corresponding to 20,000 and 20,200 metres, for the case of 250 oscillations, are in the ratio of 100 to 1·6. This means that if the radiated energy associated with a frequency band of width $\delta\omega$ at 20,000 metres is 1,000 kilowatt seconds, then 16 kilowatt seconds will be radiated at frequencies within a band of the same width at 20,200 metres.

In practice, of course, a transmission is not a single pulse as in the above example. In some cases (e.g., C.W. Morse transmission) it will consist of a sustained succession of such pulses. In others (e.g., radio-telephony) it will consist of a sustained train of carrier waves with an amplitude modulation of more or less complicated and continuously changing wave-form. Any isolated period of the transmission of finite duration can, however, be regarded as a pulse in the accepted mathematical interpretation of that word. It is inherently probable on physical grounds, and a theoretical investigation also supports the view, that if the duration of the isolated sample of the transmission be long enough, the ordinates of its energy-frequency characteristic will be proportional to the duration. If this condition be fulfilled, then the isolated element of the transmission can be regarded as a fair sample of the whole transmission from the interference point of view. The ordinates of the energy-frequency characteristic can then be divided by the time of duration of the sample, giving a mean power-frequency curve which can be regarded as characteristic for that particular transmission.

It is proposed that the mean power-frequency characteristic of a transmission, defined in the above manner, is the proper basis for the specification of the interfering capability of a transmission. This is in agreement with the view expressed in the pamphlet listed as No. 4 in the Bibliography, by Chester Snow (of the Bureau of Standards) :—

> " Undoubtedly a thoroughgoing spectrum analysis of the radiation when properly interpreted ought to furnish a logical basis for rating the interference producing qualities of a sending station."

On this basis there would be three separate elements involved in the qualification of any actual transmission of a given type in respect of its interfering capability.

(1) The determination of the ideal mean power-frequency characteristic, or, more shortly, the mean-power spectrum, of the given type of transmission.

(2) The determination, possibly by reference to an actual transmission considered to be good of its type, of the tolerance necessitated by material limitations and the existing state of the technique of the art.

(3) The determination by direct measurement of the actual mean power spectrum of the given transmission

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It is not too much to say that at the present time none of the evaluations involved in the above three steps can be carried out, except possibly the first. In view of that fact the present publication may be considered premature. In reply it may be urged that the matter is an important one and will increase in importance as

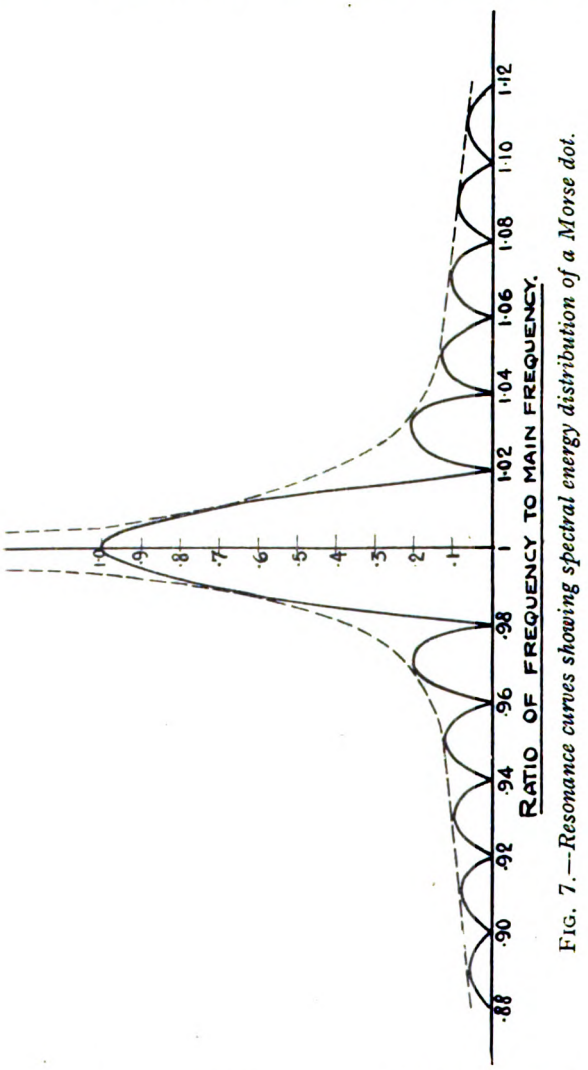

FIG. 7.—*Resonance curves showing spectral energy distribution of a Morse dot.*

time goes on and transmissions are multiplied. It is, therefore, very desirable that there should be a general understanding of the problems involved. The object of the present publication is to state these problems and to record what has so far been done toward their solution. The three elements detailed above will now be considered separately.

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7. Determination of the Ideal Mean-power Spectrum of a Transmission

The mathematical basis for this process is outlined in Appendix No. 1. It is derived for the most part from the paper No. 2 listed in the Bibliography (Appendix No. 4). Its application to any concrete case will obviously be exceedingly laborious. The simplest case will be that of pure C.W. Morse transmission. The calculation for a single Morse dot is given in detail, and the same process would be applicable to any succession of dots and dashes constituting an

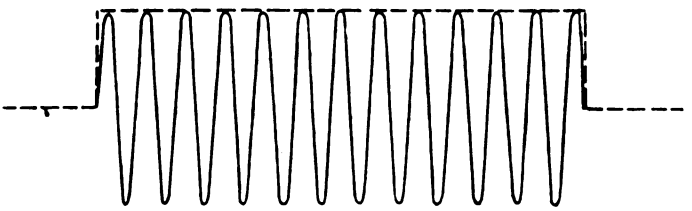

Fig. 8.—*Morse dot high-frequency signal, with square envelope.*

assumed sample of the transmission. It must be pointed out, however, that a practical difficulty arises at this point. The single dot considered as an example is assumed to have a square envelope as in Fig. 8. In practice the characteristics of the transmitting system will impose initial and final transient states which will result in an envelope of some shape such as that of Fig. 9. Now the

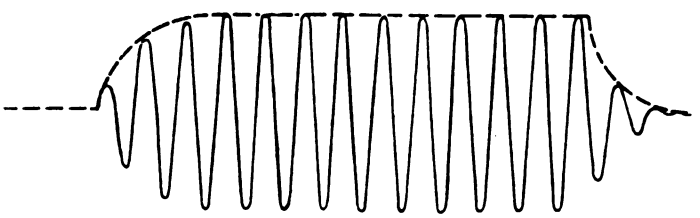

Fig. 9.—*Morse dot high-frequency signal, showing initial and final transient states.*

initial and final states play an appreciable part in determining the power spectrum of the disturbance, and very little is known at present as to the nature of these initial and final transients in actual transmitting systems. Until data on this matter are available complete calculations, even for C.W. Morse transmissions, cannot be carried out.

In the case of telephony, the difficulties are even more serious, owing to the complexity of the amplitude variation. In fact, it seems very improbable that it could ever be subject to computation

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of an exact character. However, if data were obtained as to the power spectrum of various types of modulation, e.g., speech, music, etc., it might be possible to form estimates of the limiting power spectrum of such telephony transmissions. A considerable volume of work is at present being carried out by commercial and national research laboratories on this subject.[12]

A great deal more could be said on the present aspect of the matter, but the above is sufficient to indicate the nature of the calculations involved and the considerable difficulties that have still to be overcome before they can be satisfactorily carried out.

8. Tolerance allowable to Actual Transmissions

This is the legal, commercial and international aspect of the matter and as such cannot here be fully discussed. Moreover, it obviously waits on a complete solution of the other two elements of the problem, which is very remote at present. Probably the most important single point for consideration would be whether permissible deviations from a standard should be expressed as absolute power or on a proportional basis. From the point of view of the interference actually experienced by a receiving system, the absolute magnitude of the interfering energy is the important matter, but an absolute specification would, of course, be much more drastic in effect on a high power than a low power station.

A further point involved is that not all forms of radiant energy are equally detrimental from the point of view of interference. In general, for instance, interference due to appreciable harmonics in the main frequency of the transmission will be more serious than that occasioned by the modulation of the main frequency.

In any case it must be recognised that no signal communication can be effected on a single frequency, even in the total absence of harmonics, and that any regulation restricting a station to a single frequency would, in effect, require the station to cease operations altogether.

9. Determination of the Mean-power Spectrum of an Actual Transmission

The mathematical basis of this part of the whole problem is outlined in Appendix No. 2. It will be seen that there are two main divisions of this part, namely (*a*) the determination by measurement of the mean-power spectrum of the response of a receiving system to a given transmission, and (*b*) the elimination from these experimental data of the known characteristics of the receiving circuit, leading to the mean-power spectrum of the transmission itself. These two parts will be taken separately.

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(*a*) *Determination of mean-power spectrum of response of a receiving system*

It will be seen from Appendix No. 2 that the measurement involved is the determination of the integral with respect to time of the electric energy produced in a tuned receiving circuit by the given transmission. The time of integration must be sufficiently long to satisfy the condition that the magnitude of the integral is proportional to time. To avoid the necessity for special controlled transmissions, the isolation of the sample of the transmission for measurement purposes can be effected by the closing and opening of the receiving circuit rather than by the starting and stopping of the transmission. This procedure will be justifiable as long as the time of integration is sufficiently long to render negligible the effect of the initial and final transient states in the receiving system, a condition which is included in that already stipulated. The measurement would require to be made at a sufficient number of receiving circuit tuned frequencies over the effective frequency range of the transmission to enable a curve to be drawn connecting integral mean-energy response with frequency.

The energy response in the receiving circuit will be a radio-frequency variation of more or less complicated wave-form. There is at present no known method of measuring the integral of such a quantity over appreciable periods of time. Section 10 contains a brief account of methods which have been tried at the National Physical Laboratory but without success. They are recorded simply for the information of any future experimenters on this subject.

A further point should be noted in connexion with the experimental side of this work. Apparatus of the type required will not be able to discriminate between the energy received from any given transmission and that derived from all other transmissions in simultaneous operation, nor can the contributions from all other existing transmissions be eliminated by a separate measurement in the absence of the transmission under investigation, since the energy derived from the sum of a number of separate currents is not the sum of the energies associated with each. This requires that the measurements of the response of any given transmission must be made at such a short distance from its source that the contributions from all other contemporary transmissions are relatively negligible ; but this again involves the question of whether the wave-form of a transmission changes to any appreciable extent with the distance from the source. This matter has been investigated theoretically by R. M. Wilmotte of the National Physical Laboratory, and is discussed in Appendix No. 3. It appears that in general measurements made at distances of the order of one wave-length could be regarded as satisfactory for the specification of the transmission as far as the frequency region in the neighbourhood of the main frequency of the transmission is concerned, but that this would not necessarily be true for harmonics of the main frequency. The

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matter is too complicated for any general statement on this point, and any given case would require separate consideration on the lines indicated by Wilmotte. This aspect of the matter is not, however, of very great importance as far as the legislative side of the question of interference is concerned, for harmonics are not a necessary and inevitable feature of communication in the sense that a main-frequency band is necessary and inevitable, and what is ultimately required in connexion with harmonics is not their specification within stated limits, but their total elimination. Wireless technique has already advanced very far in this direction, and the effective total elimination of harmonics is not too much to expect in the future. In the meantime, the known methods of measurement of signal strength could, if required, be adapted for the purpose of obtaining an approximate measure of the harmonic radiation.

(*b*) *The elimination of the receiving circuit characteristics from the measurements*

It is obviously desirable that the specification of a transmission should be stated in terms of the characteristics of the transmission alone, without reference to those of any receiving circuit with which the necessary measurements had been carried out. The matter is very clearly described in the paper by Chester Snow[4] from which the following quotation is taken :—

> " If the radiation from a given sending radio station is received simultaneously by a set of receiving circuits whose constants are properly chosen, the arrangement constitutes a spectroscope. . . . Or if the message can be repeated, a single circuit may be used and its constants varied. . . . When the circuit possesses very high selectivity, so that it may be considered to respond to a definite frequency only, then if it be tuned successively to various frequencies and the mean square of the current be measured for each, this will be proportional to the spectral distribution of intensity in the radiation. Such an ideal case is not always attainable in practice. The observed current as a function of frequency is often profoundly affected by the character of the receiving circuit. The resonance curve of every circuit possesses a finite width, due to the fact that there is a dissipation of energy in the circuit. A spectral structure in the radiation, which is fine compared to the resonance curve of the circuit, may be entirely masked. The problem which then presents itself is to find how the circuit impresses its character upon the record in order to make corrections for it, and draw inferences as to the character of the radiation which may be, at first glance, entirely hidden in the observations. It is analogous to attempting to resolve a light source by means of a spectrum of insufficient resolving power, where one makes up for lack of resolving power

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by a quantitative study of the energy distribution in the record. . . ."

The necessity for eliminating the characteristics of the receiving systems from the measurements made therewith, was recognised in the original equivalent decrement proposals, where it was suggested that this object could be achieved by the simple subtraction of the decrement of the receiving circuit from the apparent " equivalent decrement " of the transmission as measured with the given receiving circuit. Now it can be shown that in certain ideal simple cases (e.g., trains of exponentially damped oscillations) this procedure has some degree of theoretical justification and should result in approximately the same value for the " equivalent decrement " of the transmission, whatever the decrement of the receiving system on which it is measured. In general, however, this simple process has no theoretical justification whatever, and would in many cases give rise to completely misleading conclusions. As an apparent way out of a difficulty, the proposal has an attractive simplicity, but it cannot be too strongly emphasised that it is in general an entirely arbitrary proceeding and is in no useful sense a solution of the problem.

The mathematical basis of the quantitative study referred to in the above quotation is outlined in Appendix No. 2. It is essentially a matter of finding the solution of a certain type of integral equation. This has been studied by mathematicians, but for the most part the existing purely mathematical work on this subject is of academic rather than of practical value. Some more practical types of solution are given in the paper by Snow,[4] which paper is, in fact, wholly devoted to this aspect of the interference problem. The matter has hardly as yet received the attention it deserves, for it is only in recent years that it has entered the region of applied science. It is to be hoped that further research will be devoted to the matter by mathematicians with a view to arriving at as simple and practicable a solution as may be possible within the limitations of the problem.

In connexion with this same aspect of the matter it should be noted that a further possibility exists, namely, the utilisation of a resonant receiving system of such high selectivity (i.e., low damping) that it can be considered to be virtually a line spectroscope. In other words, a receiving system of such high resolving power that the spectrum of its response can be regarded as a copy of that of the excitation. The construction of a plain inductance and capacity receiving system of this character is impossible, short of using solid mercury coils at the temperature of liquid helium, but there are mechanical resonant systems which can be considered to approximate sufficiently closely to it for practical purposes. Two examples suggest themselves immediately, the quartz crystal, operated piezo-electrically, and a long steel rod in end vibration. A few notes on the experimental aspect of this possibility will be found in Section 10.

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10. The Experimental Measurement of the Mean-power Spectrum of a Transmission

It has been shown in Appendices Nos. 1 and 2 that the measurement of the mean-power spectrum of a transmission requires the measurement of the integral with respect to time of the square of the current induced in a receiving system, the measurement being made at a sufficient number of settings of the tuning adjustment of the receiving system to enable a smooth curve to be drawn through the graphed observations. The time of integration cannot be specified beforehand, but must be such that the value of the integral is proportional to time.

As already stated, there is at present no instrument available for this measurement, and it appears that the practical application of the ideas developed in this Report must await the development of suitable apparatus. In the meantime it will be well to record briefly the negative results of experimental work devoted to this end at the National Physical Laboratory, for the information and guidance of any future workers on this subject.

Two possibilities have been investigated. The first was in effect a balanced air-thermometer method. Two glass bulbs, of about 5 cm. diameter, were connected by a U-tube manometer containing aniline or a light oil. Provision was made for either bulb to be opened to the atmosphere. The bulbs were silvered internally and each was enclosed in a wooden box packed with cotton wool. Into each bulb was sealed a resistance element (5 to 10 ohms) with low resistance sealing wire electrodes brought out through the walls of the bulbs. Fig. 10 will give some idea of the instrument. The idea of the method was that if sufficiently good thermal insulation of the bulbs could be attained the displacement of the liquid column in the manometer tube would be proportional to

$$\int_0^t i^2\,dt,$$

where i is the current passed through one of the resistance elements.

To test the apparatus a constant current was passed through one element and the displacement of the manometer column recorded against time. It was found that the displacement increased fairly rapidly for a few seconds and thereafter remained nearly constant, increasing very slowly indeed. This indicated that after a few seconds an equilibrium was established between the energy supplied and that lost through imperfect thermal insulation. It was considered that the probability of the attainment of sufficiently perfect thermal insulation was not enough to justify the further prosecution of the idea. Moreover, the instrument would not have been very conveniently applicable to the immediate problem, owing to the difficulty of re-establishing a thermal equilibrium between the two bulbs between successive measurements.

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A second method that was tested was the use of a Grassot fluxmeter in association with a thermo-junction. The fluxmeter is essentially a highly damped galvanometer with control reduced to the practicable minimum. The theory of this instrument indicates that its deflection should be proportional to the quantity of electricity passed through it, provided certain conditions are

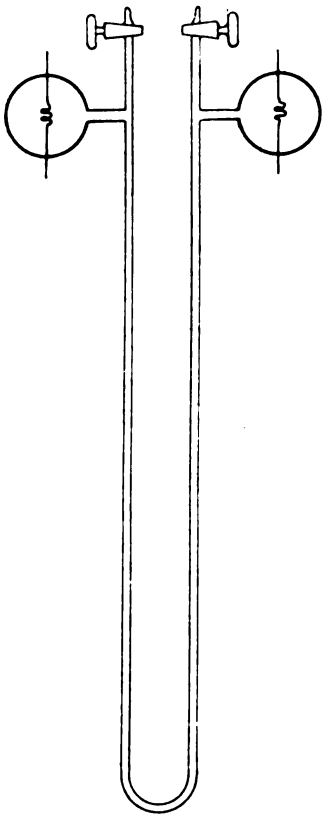

FIG. 10.—*Air-thermometer for measurement of current.*

fulfilled. Its possible applicability to the present problem was tested by passing through the instrument small currents of known amount for various different time intervals up to a total of from 5 to 20 seconds. The actual time intervals were measured very accurately to a tenth of a second by means of a drum recorder. A comparison of coulombs with deflection, however, showed that the deflection per coulomb was by no means constant, varying by 50 per cent. or more in a manner depending on the actual time distribution of the current. A further investigation of the theory of the instrument indicated, as the probable explanation of this

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variation, that the instrument can only be expected to integrate in the manner desired if the moving system comes completely to rest in the time interval between successive impulses. That condition was not fulfilled in the test measurements and would not be fulfilled in a reception measurement. The method was, therefore, abandoned.

A further possibility is the association of a thermo-junction and some form of recording string galvanometer or oscillograph. This, however, would involve the integration of the record by some mechanical means and would be exceedingly laborious when applied to a large number of measurements.

It might be mentioned that a method of a totally different character has also been considered, one which at first sight appears to eliminate the integral equation from the problem. This is the utilisation of the high selectivity attainable with certain mechanical resonant systems, e.g., a long steel rod in end vibration. The idea is, briefly, the transformation of the radio-frequency components of the transmission to the resonant frequency of the mechanical resonant system, which can then be used, in effect, as a spectroscope of such high resolving power that the width of its own frequency band can be neglected.

There are, however, many serious practical difficulties in the realisation of this method, and in addition one theoretical objection which invalidates the idea. Whatever method of heterodyne transformation is employed, using a pure sine wave local oscillation of frequency $\omega/2\pi$, the resonant system will respond to any constituent frequency $\omega^1/2\pi$ of the signal current which satisfies the equation

$$\omega \sim \omega^1 = n,$$

where $n/2\pi$ is the resonant frequency of the resonant system. There are two values of ω^1, namely $(\omega \pm n)$ which satisfy this equation. Thus the spectrum of the transmission is analysed, not with a line, but with two lines, $2n/2\pi$ cycles apart, or rather with two very narrow bands of the same separation. This will not be very serious if n is very small compared with ω, but that condition cannot always be fulfilled.

In addition, the response of the mechanical resonant system will be of a character which is not readily measurable or interpretable. In fact, it is difficult to see how any satisfactory measure of the energy of its oscillation can be obtained without some sort of integrating apparatus of the kind required for the other suggested method.

It should already be clear that the experimental side of the measurement contemplated in this Report presents difficulties towards the solution of which very little progress has yet been made. It is to be hoped, however, that work will continue to be directed to this end as the advance in technique which is required would be of great value in itself, apart from the immediate objective. An integrating instrument of the characteristics described above would certainly find very useful application in many other fields.

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11. Conclusion

It is hoped that the above cursory review will have served to indicate both the importance of the subject of the mutual interference of wireless transmissions and the difficulties which at present lie in the way of its effective control by international regulation. The distinctive feature of the matter, which is at the same time the origin of these difficulties and the reason why they are still unsolved, is that the source of interference is not the periodic and quasi-stationary element of the transmission, but the non-periodic and transient elements. Periodic phenomena are fairly well understood and a practical technique is ready to hand for their quantitative specification. This is the well mapped field of Fourier's theorem. Interference problems, on the other hand, take us into the relatively unexplored field of Fourier's integral. Here both theory and technique are comparatively undeveloped, probably because of the less obvious practical significance of these branches of mathematics and electricity, and because of the greater complexity of the theory and the much greater difficulty of the technique involved. This review will have served a very useful purpose if it stimulates a wider interest in this unexplored region.

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APPENDIX 1

THE FREQUENCY ANALYSIS OF THE INTENSITY OF AN ELECTRIC FIELD

LET $E(t)$ be the instantaneous value of the electric intensity at time t at some point in space. Its variation with time is quite unspecified except that its total integral

$$\int_{-\infty}^{\infty} E(t)\, dt$$

is finite. Subject to this condition, it can be expressed (by Fourier's Integral Theorem) in the form

$$E(t) = \frac{1}{\pi}\int_0^{\infty} d\omega \int_{-\infty}^{x} E(\mu) \cos\omega\,(\mu - t)\, d\mu$$

where μ is a variable of integration.

This holds for all values of t. To demonstrate the physical significance of the right-hand side, it can be written

$$E(t) = \frac{1}{\pi}\int_0^{\infty} (a\, d\omega \cos\omega\, t + b\, d\omega \sin\omega\, t)$$

where

$$a = \int_{-\infty}^{\infty} E(\mu) \cos\omega\ \mu\, d\mu \text{ and } b = \int_{-\infty}^{\infty} E(\mu) \sin\omega\mu\, d\mu.$$

The elements $a\, d\omega$ and $b\, d\omega$ define in amplitude and phase a sine wave intensity of frequency $\omega/2\pi$ and lasting for all time. The total intensity is expressed as the sum of an infinite series of such sine wave components, corresponding to a continuous distribution over the whole spectrum.

A form which is more compact and convenient for manipulation can be obtained by utilising the properties of complex or "two dimensional" numbers.

From the above definitions of a and b

$$a - j\,b = \int_{-\infty}^{\infty} E(\mu)\epsilon^{-j\omega\mu}\, d\mu$$

and

$$E(t) = \text{real part of } \frac{1}{\pi}\int_0^{\infty} (a - j\,b)\epsilon^{j\omega t}\, d\omega.$$

Thus the complex number

$$X(\omega) = a - j\ b = \int_{-\infty}^{\infty} E(\mu)\epsilon^{-j\omega\mu}\, d\mu$$

is characteristic of the given intensity variation $E(t)$ and expresses its spectral distribution.

If the intensity is zero or effectively zero for all values of t outside the range t_1 to t_2, then

$$X(\omega) = \int_{-\infty}^{\infty} E(\mu)\epsilon^{-j\omega\mu}\, d\mu = \int_{t}^{t_2} E(\mu)\epsilon^{-j\omega\mu}\, d\mu.$$

(Conversely it can be shown by the theory of contour integration that, subject to the convergence of the integrals concerned, the artificial function

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$f(t)$ which is zero for all values of t outside the range t_1 to t_2 and within this range has the same values as some analytic function $\phi(t)$, can be represented by

$$f(t) = \text{real part of } \frac{1}{\pi} \int_0^\infty \epsilon^{-j\omega t}\, d\omega \int_{t_1}^{t_2} \phi(\mu) \epsilon^{-j\omega\mu}\, d\mu.$$

In other words, the expression on the right has the useful property that it vanishes for all values of t outside the given range and is equal to $\phi(t)$ for all other values of t. This representation has not hitherto received the attention it deserves in relation to the analysis of circuit problems.)

Suppose now that $E(t)$ is zero outside the range t_1 to t_2 and for all other values is given by

$$E(t) = \sum_{n=1}^{n=\infty} (\alpha_n \cos n\,p\,t + \beta_n \sin n\,p\,t)$$

Then

$$X(\omega) = \int_{t_1}^{t_2} \left(\sum_{n=1}^{n=\infty} \alpha_n \cos n\,p\,\mu + \beta_n \sin n\,p\,\mu \right) \epsilon^{-j\omega u}\, d\mu.$$

If the magnitude $|\, X(\omega)\,|$ be plotted against ω, it will be found, in general, that the curve will have pronounced peaks in the neighbourhood of those values of ω for which $\omega = np$, $n = 1, 2, 3$, &c. The greater the magnitude of $t_2 - t_1$ (compared with $2\pi/p$) the more pronounced will these peaks become, until ultimately, when $t_2 - t_1$ is very large indeed, the curve will approximate to a discontinuous series of isolated ordinates such that for any given integral value of n

$$\alpha_n^2 + \beta_n^2 \simeq a(\omega)^2 + b(\omega)^2$$

where $a(\omega)$, $b(\omega)$ are the values of a and b corresponding to $\omega = np$. Thus, Fourier's theorem is really a special limiting case of the more general proposition known as Fourier's Integral. Interference problems lie in the region where the time interval $t_2 - t_1$ is not in general sufficiently large compared with the main frequency $p/2\pi$ for the ordinates outside the peaks to be neglected, and the more general integral proposition has, therefore, to be applied instead of the simple special case.

The analysis can be illustrated by reference to the case of n complete sine waves, i.e.,

$$\begin{aligned} E &= \hat{e} \sin pt \text{ for } 0 \leqslant t \leqslant n\mathrm{T}\ (\mathrm{T} = 2\pi/p) \\ &= 0 \text{ for all other values of } t. \end{aligned}$$

$$X(\omega) = \hat{e} \int_0^{n\mathrm{T}} \sin p\mu\, \epsilon^{-j\omega\mu}\, d\mu$$

$$= \hat{e} \left[\frac{\epsilon^{-j\omega\mu}}{p^2 - \omega^2} (p \cos p\mu + j\omega \sin p\mu) \right]_0^{n\mathrm{T}}$$

$$= 2\hat{e} \frac{j\,p\,\epsilon^{-j\pi n\omega/p}}{p^2 - \omega^2} \sin \frac{\pi n \omega}{p}.$$

It will be more convenient to put $\frac{\omega}{p} = m$, so that $X(mp)$ defines the amplitude and phase of the element having a frequency m times that of the main frequency.

$$X(mp) = \frac{2\hat{e}}{p} \frac{j \sin \pi mn}{1 - m^2} \epsilon^{-jmn\pi}.$$

Therefore

$$|\, X(mp)\,| = \frac{2\hat{e}}{p} \frac{\sin \pi mn}{1 - m^2}.$$

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Note that

$$\lim_{m \to 1} | X(mp) | = \frac{2\mathscr{E}}{p} \lim_{m \to 1} \frac{n\pi}{1+m} \left| \frac{\sin n\pi(1-m)}{n\pi(1-m)} \right| = \frac{n\pi\mathscr{E}}{p}.$$

Thus

$$\frac{| X(mp) |}{| X(p) |} = \frac{2}{n\pi} \left| \frac{\sin \pi mn}{(1-m^2)} \right|.$$

This ratio, considered as a function of m, has a maximum value 1 when $m = 1$ (i.e., at the main or transmitter frequency, and a series of maxima on either side of this main peak, these subsidiary maxima occurring in the neighbourhood of points for which

$$| \sin \pi mn | = 1$$

$$\text{i.e.,} \quad m = \frac{2r+1}{2n} \qquad r = 1, 2, 3, \text{ \&c.},$$

$$\text{or} \quad \omega = (2r+1)\frac{p}{2n}.$$

The ratio is shown plotted against m for $n = 50$ in Fig. 6. Notice that the peaks occur at frequencies differing by $\frac{1}{nT}$ cycles per second, so that the shorter the number of complete cycles the closer they will be. Notice further that apart from the sine wave fluctuation given by the sine πmn term, the ratio is inversely proportional to n, so that the greater the total number of complete oscillations in the original excitation, the more nearly does it approach a single frequency disturbance, a conclusion which is otherwise obvious. It also shows, however, that a comparatively small number of oscillations will have a very appreciable spectral spread, and is by no means a single frequency disturbance.

We must now consider the relation of the above to the spectral distribution of the energy of any given excitation. For a given field intensity $E(t)$ the instantaneous energy per unit volume of the medium is proportional to $E(t)^2$, and the total energy of the complete excitation will be proportional to

$$\int_{-\infty}^{\infty} E(t)^2 \, dt$$

per unit volume, or if $E(t)$ is zero except between t_1 and t_2, to

$$\int_{t_1}^{t_2} E(t)^2 \, dt.$$

Now

$$E(t) = \text{real part of } \frac{1}{\pi} \int_0^{\infty} (a - jb) \epsilon^{j\omega t} \, d\omega$$

where

$$a - jb = \int_{t_1}^{t_2} E(\mu) \epsilon^{-j\omega\mu} \, d\mu$$

(i.e., a and b are functions of ω but not of t).

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Multiplying the above equation by $E(t)\,dt$ and integrating from t_1 to t_2 gives

$$\int_{t_1}^{t_2} E(t)^2\,dt = \text{real part of } \frac{1}{\pi}\int_0^{\infty} d\omega.\quad a - jb\int_{t_1}^{t_2} E(t)\epsilon^{\,j\omega t}\,dt,$$

and since

$$\int_{t_1}^{t_2} E(t)\epsilon^{\,j\omega t}\,dt = a + jb$$

$$\int_{t_1}^{t_2} E(t)^2\,dt = \text{real part of}\frac{1}{\pi}\int_0^{\infty}(a^2 + b^2)\,d\omega$$

$$= \frac{1}{\pi}\int_0^{\infty}(a^2 + b^2)\,d\omega = \frac{1}{\pi}\int_0^{\infty} |\,X(\omega)\,|^2\,d\omega.$$

The energy distribution is, therefore, proportional to the square of the ordinates of the $|\,X(\omega)\,|$ curve, and $|\,X(\omega)\,|^2$ may legitimately be termed the energy spectrum of the disturbance. In fact $|\,X(\omega)\,|^2$ is proportional to the energy per unit volume of the medium per unit range of the spectrum. It is a function of frequency and of the shape of the disturbance, but is not a function of time.

It is proposed in this report that $|\,X(\omega)\,|^2$, determined experimentally for an element of any actual transmission of such duration (t_1 to t_2) that

$$|\,X(\omega)\,|^2 \propto t_2 - t_1$$

for any value of ω, is the proper basis for rating the interference producing capability of the transmission.

If the above condition is satisfied, $|\,X(\omega)\,|^2/(t_2 - t_1)$ plotted as a function of frequency, can be described as the mean-power spectrum of the transmission.

It is now necessary to consider how the response of a tunable circuit of known constants depends upon $X(\omega)$ and can be utilised for its determination. This is considered in Appendix No. 2.

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APPENDIX 2

THE RESPONSE OF A RESONANT SYSTEM TO AN IMPULSIVE EXCITATION

CONSIDER a quantity $E(t)$, which is an " artificial " function of time, that is to say, a function which is represented by different analytic functions for various ranges of t. Suppose it to be zero, or negligibly small, for all values of t outside a range t_1 to t_2 and identical in magnitude with some analytic function $\phi(t)$ for all other values of t.

It has been shown that $E(t)$ can be expressed in the form

$$E(t) = \text{real part of } \frac{1}{\pi}\int_0^\infty X(\omega)\epsilon^{j\omega t}\,d\omega,$$

where

$$X(\omega) = \int_{-\infty}^{\infty} E(t)\epsilon^{-j\omega t}\,dt.$$

For purposes of computation, we have

$$\int_{-\infty}^{\infty} E(t)\epsilon^{j\omega t}\,dt = \int_{t_1}^{t_2} \phi(t)\epsilon^{j\omega t}\,dt.$$

This, however, is incidental, and attention will be confined to the integral in terms of the artificial function $E(t)$.

As already explained, this form of representation expresses $E(t)$ as the sum of an infinite number of infinitesimal simply periodic terms $X(\omega)\,d\omega\,\epsilon^{j\omega t}$.

It is important in relation to what follows to realise that the formula from which $X(\omega)$ is computed implies that each of these infinitesimal simply periodic elements is infinite in duration, with its time origin at minus infinity. In other words, the impulsive disturbance is, so to speak, a resultant interference pattern produced by an infinite number of simply periodic terms, each of which began at $-\infty$ in time. Up to the time t_1, the interference between all these elements is complete and results in a zero magnitude. From t_1 to t_2 the resultant is the analytic function $\phi(t)$, and from t_2 onwards the terms annul each other again and give a zero resultant.

The response of a resonant system to such an excitation can now be considered. A circuit consisting of an inductance L, a resistance R and a capacity C in series with a source of electro-motive-force can be taken as a simple example. Representing the e.m.f. as the real part of $(a - jb)\ \epsilon^{j\omega t}$ it is well known that the response of the circuit can be expressed as the sum of two terms. The first is proportional to $\epsilon^{j\omega t}$ and represents a quasi-stationary state of forced oscillation. The second will be proportional to $\epsilon^{(-\alpha + jp)t}$, where α and p are positive numbers depending on L, C and R only. This represents a free oscillation with an exponentially decreasing amplitude. If the origin of time is at minus infinity, the magnitude of this second term will be zero at any current instant t on account of the term $\epsilon^{-\alpha t}$. (It must be remembered that t functions both as a current co-ordinate and a measure of duration. If the origin of t is at $-\infty$, t is infinite at any given instant and $\epsilon^{-\alpha t} = 0$.) Thus, if the origin of t is at $-\infty$, the first term alone (i.e., the forced oscillation) will completely represent the response of the circuit at any current instant t. In other words, the free oscillation started so long ago that it has already decreased to zero.

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If, therefore, the origin of t is at minus infinity, the current flowing in the circuit can be completely represented by

$$i = \text{real part of } \frac{(a - jb)\epsilon^{j\omega t}}{R + j(\omega L - 1/\omega C)},$$

$$\text{i.e., } i = \text{real part of } \frac{\omega}{L\{2\omega\alpha + j(\omega^2 - \omega_0^2\}} (a - jb)\epsilon^{j\omega t}$$

where

$$\alpha = R/2L$$

and

$$\omega_0^2 = 1/LC.$$

Whatever the character of the resonant system, the current i will be of the form

$$i = \text{real part of } Y(\omega, \omega_0)(a - jb)\epsilon^{j\omega t}$$

where $Y(\omega, \omega_0)$ is a complex number depending on ω and ω_0, ω_0 being a quantity which can be varied continuously by a suitable continuous variation of one of the constants of the circuit (e.g., C).

With the above introduction it is easy to see that the total response of the circuit to an excitation $E(t)$ of the character described above can be obtained by the summation of elementary responses derived from the elements $X(\omega)\epsilon^{j\omega t}\, d\omega$, i.e.,

$$i = \text{real part of } \frac{1}{\pi}\int_0^\infty Y(\omega, \omega_0)\, X(\omega)\epsilon^{j\omega t}\, d\omega.$$

It is important to realise that this is the complete solution of the second order differential equation involved, comprising in a single expression both the complementary function and the particular integral.

From the present point of view, the desired quantity is not i but the integral energy of the response, i.e.,

$$Q = \int_0^\infty i^2\, dt.$$

It is easy to show, exactly as in Appendix 1, that

$$Q = \frac{1}{\pi}\int_0^\infty |Y(\omega, \omega_0)|^2\, |X(\omega)|^2\, d\omega$$

or, since Q will be a function of ω_0, i.e., will depend on the frequency to which the resonant system is tuned,

$$Q(\omega_0) = \frac{1}{\pi}\int_0^\infty |Y(\omega, \omega_0)|^2 |X(\omega)|^2\, d\omega.$$

The proposal outlined in this Report is that $|X(\omega)|^2$, a function of ω depending on the shape of the excitation $E(t)$ is the proper basis for rating the interference producing capabilities of $E(t)$. The experimental measurement involved is the determination of $Q(\omega_0)$ for a sufficient number of values of ω_0 to enable a smooth curve to be drawn exhibiting Q as a function of ω_0. The quantity $|Y(\omega, \omega_0)|^2$ can be regarded as known for any given receiving circuit. It is in any case determinable by laboratory measurements. The final problem is, therefore, the solution of the above integral equation for $|X(\omega)|^2$. It is obviously of the type

$$F(x) = \int_0^\infty G(x, y) f(y)\, dy$$

where F and G are known and f is to be determined, and is known as an integral equation of the first kind.

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The mathematical solution of this equation is known and is discussed, for example, in Whitaker's *Modern Analysis* and Bôcher's *Introduction to Integral Equations*. Such mathematical solutions are, however, not readily applicable to the present problem, since $F(x)$ is not known as an analytic function, but as a curve of more or less complicated shape which may not be conveniently expressible as an explicit analytic function.

A very good start in this problem has been made by Chester Snow in the paper already referred to, but there is scope for considerable further research in this subject.

To some extent this research waits on a satisfactory solution of the experimental part of the problem, in order that information may be available as to the kind of $F(x)$ curves that will be encountered in practice. No such measurements have yet been made—at least, none have been published. It is true that two experimental curves were given in Chester Snow's paper, but these cannot be regarded as really representative of practical transmission curves. No integrating apparatus was used, the receiving circuit response being measured on a hot wire ammeter. This restricts the type of signal e.m.f. to one that will give a constant reading on such an instrument. Such curves are only of value in affording experimental confirmation of the methods of solution of the integral equation described in the text.

Chester Snow's paper is, nevertheless, a very valuable contribution to this subject, and should be consulted by any who wish for information on the practical aspect of the matter.

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APPENDIX 3

THE EFFECT OF DISTANCE ON THE SPECTRUM OF A TRANSMISSION

By R. M. WILMOTTE, B.A., A.M.I.E.E.

AN antenna system with given surroundings will, when suitably excited, transmit electro-magnetic waves of any desired frequency. The field strength at any point will depend on this frequency and there are many causes which may produce considerable and somewhat complicated variation of field strength with frequency.

As already explained in the body of this Report, a signal of finite duration transmitted from the antenna can be interpreted as the resultant of trains of sine waves of constant amplitude and of infinite duration and, theoretically, of all frequencies, but in practice of all frequencies included in a certain band of finite width centred on the main or nominal frequency of the transmission. Each component will be transmitted in a somewhat different manner from that of every other component of different frequency. The spectrum of the radiation at any given point will, therefore, depend to some extent on the position of that point relative to the antenna.

This fact constitutes a difficulty in obtaining a suitable definition of the interfering capability of the radiation and in devising a method for measuring it. It is the object of this Appendix to consider briefly this aspect of the matter.

If all the effects to be discussed below could be calculated, a knowledge of the spectrum at any point would be sufficient for the calculation of the spectrum at all other points, and the difficulty of finding a suitable expression for the measurement of interference would disappear. In certain simple cases, the calculation can be carried out to a sufficiently close degree of approximation, but in general the work involved would be prohibitively laborious.

The various factors which give rise to a variation of the spectral constitution of the radiation with distance will now be considered separately, in order to obtain some idea of the nature and degree of the variation, and to find whether, in any given case, it may or may not be neglected. The matter can only be outlined here. A more detailed account will be found in the author's paper on the subject, published in the *Journal of the Institution of Electrical Engineers*.[14]

(*a*) *Proximity Effect*

The existence of a variation in the spectrum with distance from the transmitter can readily be seen from Hertz's equations. The field strength at any point due to the radiation from a current element $i\delta s \sin \omega t$ of length δs, situated at the origin and along the Z axis can be expressed in the usual polar co-ordinates in the form :

$$H_r = H_\theta = E_\phi = 0$$

$$H_\phi = \frac{i\delta s \sin\theta}{cr}\left\{\frac{1}{r}\sin\omega\left(t-\frac{r}{c}\right)+\frac{\omega}{c}\cos\omega\left(t-\frac{r}{c}\right)\right\}$$

$$E_\theta = \frac{i\delta s \sin\theta}{r}\left\{\frac{1}{cr}\sin\omega\left(t-\frac{r}{c}\right)+\omega\left(\frac{1}{c^2}-\frac{1}{\omega^2 r^2}\right)\cos\omega\left(t-\frac{r}{c}\right)\right\}$$

$$E_r = \frac{2i\,\delta s\cos\theta}{r^2}\left\{\frac{1}{c}\sin\omega\left(t-\frac{r}{c}\right)-\frac{1}{\omega r}\cos\omega\left(t-\frac{r}{c}\right)\right\}$$

where c is the velocity of light.

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From the present point of view the interesting fact about these equations is that at a given distance the field depends on the frequency. Now a complex current variation of the type considered in this Report will in effect radiate energy at all frequencies comprised within a certain band of finite width. The field due to any one constituent frequency component will be radiated in accordance with the above equations, and will, therefore, vary with the position of the point considered. The variation with position will, however, be different for each frequency. Thus the spectrum will vary with the position of the point considered. Moreover, since the equations for H_ϕ, E_θ, and E_r are different the spectrum of each of these components will vary with the position of the point.

As the distance is increased the energy of the radiation tends towards a spectral distribution which will be the same for E_θ or H_ϕ. (The component E_r will become negligibly small.) In fact, for distances greater than one wave-length the spectral distribution may be taken as constant with respect to distance. Even then the spectrum of the field will not be the same as that of the current in the antenna. A component differing in frequency from the fundamental by m per cent. will produce a signal strength which will be effectively m per cent. larger.

The above equations refer to a current element only, and in general the total field strength due to the whole antenna would have to be found by an integration process. At distances large compared with the aerial, however, the current element formulæ can be utilised, treating the whole antenna as an element.

It is interesting to note that an effect similar to that described above has been noticed in acoustics. C. F. Sacia [13] mentions that ". . . a difference in quality of transmitted speech can be detected when the speaker's lips are within 2 cms. of the transmitter diaphragm."

A further factor, intimately related to the one considered above, may be effective in certain cases. The distribution of the current in the aerial depends to some extent upon frequency. For a complex excitation of the kind considered, the spectral constitution of the current in any current element will depend to some extent on the position of that element in the antenna system. This aspect of the matter is described in the next section.

(*b*) *Effect of Directivity*

With few exceptions, unless an antenna extends over a distance comparable with a wave-length, the directive effects are negligible. Small changes of frequency will, in general, produce very small changes of directivity, even in many sharply directive systems, but if the spectrum band extends over a wide range of frequency ($\pm$ 20 per cent., say), very different directive effects may be found between the fundamental and the more distant frequencies.

In sharply directive systems, the various portions of the system are usually so adjusted that the radiations from them add in a given direction. In that case, a small variation of frequency will produce but a second order change in the intensity in that direction. When this condition is not fulfilled, sharply directive systems may produce enormous changes in directive effects for comparatively small changes of frequency. There are, moreover, certain antenna systems, such as the Franklin system, in which part of the current loops are cancelled as far as radiation is concerned. In such cases, a relatively small change in the frequency, may considerably alter the current distribution and produce appreciably different directive effects.

It is evident that any variation of the directive effects with frequency will produce different spectra in different directions. Now the change in directivity may not only be in the horizontal plane but also in the vertical. This may be of importance, for a beam sent upwards will be reflected back to earth, so that, at a distance from the antenna, the spectrum may be very different owing to downcoming waves.

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(*c*) *Effect of Earth*

The resistivity and dielectric constant of the earth have different effects on waves of different frequency. Waves of some frequencies may be absorbed and reflected differently from others.

It is clear from all the preceding considerations that any measurement of the spectral distribution of the radiation of a given transmission, with a view to rating its interfering capability, would require to be supplemented by an investigation of the possible variation of this distribution with distance.

Apart from the present application to the problem of interference, this aspect of the radiation process is of general interest, particularly in relation to transmissions having an appreciable spectral spread.

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APPENDIX 4

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